Evaluation of media influence and practical applications for the use of Static Low Density Media filters in domestic wastewater treatment

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EVALUATION OF MEDIA INFLUENCE AND PRACTICAL APPLICATIONS FOR THE USE OF STATIC LOW DENSITY MEDIA FILTERS IN DOMESTIC WASTEWATER TREATMENT

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ABSTRACT

Static Low Density Media filters have been used over the past two decades for nitrification and solids removal in high-density recirculating aquaculture systems. The SLDM filters are submerged biofilters which contain a plastic media with a density less than that of water. The media beds remain packed, or static, during operation except for periodic expansion of the bead bed during a backwash. More recently SLDM filters have been evaluated for secondary clarification of domestic wastewater where concurrent biological treatment and particulate removal occur within one unit. Recirculation is accomplished using airlifts which provide external aeration coupled with multiple pass removal of $CBOD_5$ and TSS enhancing biofiltration performance. The following field study investigated the impact of filter media characteristics on the performance of SLDM filters in addition to an evaluation of their practical applications.

Data from bench scale SLDM filters identical in configuration, but employing different media are reported. The media used were a boat-shaped (EN) media and a cylindrical KMT (Kaldness carrier) media. The units were fed effluent from a primary clarifier with a mean $CBOD_5$ concentration of 104 mg/l and TSS concentration of 77 mg/l. Results indicate over 90% reduction in $CBOD_5$ and TSS when subjected to an organic loading range between 1-2 kg/m^3.day using EN media. Over an 80 % reduction in $CBOD_5$ and TSS levels were achieved using the SLDM unit with KMT media at the same organic loading range. Findings also indicated a significantly higher mean oxygen uptake rate of 1.8 kg/m^3.day for the EN media, which was twice that of the KMT media.

Data are also reported from a study where multiple SLDM configurations were used for domestic wastewater treatment. Each application was unique in regards to the

treatment objective. Removal of $CBOD_5$, TSS, and TAN were achieved with the placement of each experimental unit within the treatment train.

SLDM filters can be applied successfully for treatment of domestic wastewater. Proper media selection in conjunction with operating techniques can enhance performance of the filter. Specialized treatment is accomplished to meet objectives with a general hull design. The simple operation of SLDM filters using the external aeration strategy is a robust treatment alternative and particularly well suited for applications where space or service opportunities are limited.

CHAPTER 1: INTRODUCTION

The fundamental components of primary clarification, biological treatment, and secondary clarification of domestic wastewater have been traditionally used as separate unit operations. Static Low Density Media Filters allow the consolidation of the classical treatment train into a simpler, more compact treatment approach. Concurrent biological treatment and the physical removal of particulate matter occur in one simple robust unit. Savings in capital and operating costs for single components serving multiple duties can overcome the losses of individual process efficiencies.

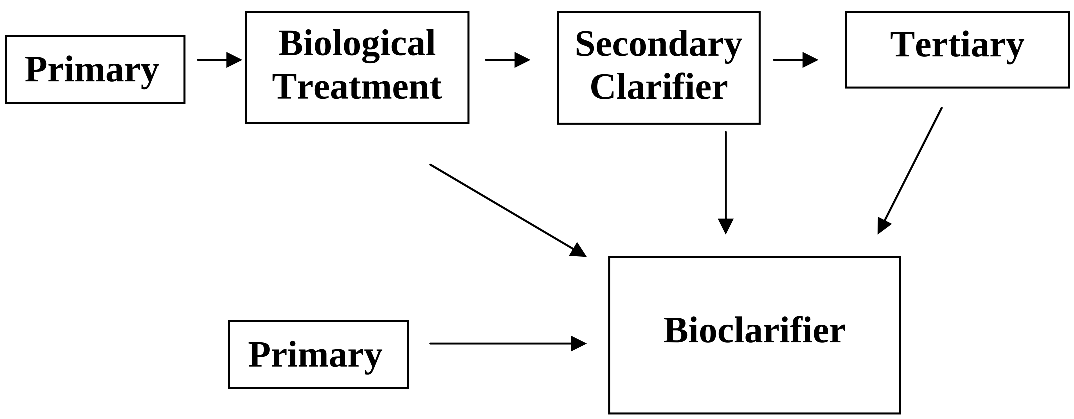


Figure 1-1. The consolidation of multiple unit operations into one bioclarifier simplifies the treatment strategy.

According to the U.S. Census Bureau more than 60 million people live in small communities, such as rural towns, villages, and coastal dwellings and depend on onsite/decentralized domestic wastewater treatment systems. Significant population growth has created a demand for a more economical and robust domestic wastewater treatment technology without compromising effluent quality. The application of SLDM filters for these communities eliminates the complexity and spatial limitations of extensive plant designs based on multiple unit operations by combining biological treatment, secondary clarification, and tertiary treatment into one bioclarifier.

STATIC LOW DENSITY MEDIA FILTERS

Static Low Density Media (SLDM) filters have been used extensively in the aquaculture industry as the core treatment component of the more commonly known "Floating Bead Filters". The floating bead filters (FBF's) are expandable granular filters that display a bioclarification behavior similar to sand filters (Malone et al. 2000). The units are now widely employed as clarifiers or bioclarifiers in support of high-density recirculating production and holding systems for fish, reptiles, and crustacea (Malone and Beecher, 2000; DeLosReyes and Lawson, 1996). Floating bead filters are normally operated with the floating bed in a packed or static mode. In the packed bioclarification mode, the units concurrently provide solids capture, carbonaceous BOD removal, and nitrification. During the packed or filtration mode, influent wastewater enters below the media bed. With the aid of recirculation, the wastewater is passed through the static media bed 80 to 90 times before it is discharged. Recirculation and external aeration is accomplished using airlifts, achieving multiple pass removal with one pass retention times between 30 seconds to 1.5 minutes per pass. In

Figure 1-2. Currently available floating bead filters contain a granular media which provide concurrent physical and biological treatment (Aquaculture Systems Technologies, 2003)

addition to multiple pass removal of substrates, recirculation with an airlift provides external aeration making it a very critical management tool.

When the underlying layers of bacteria are unable to extract the necessary amount of dissolved oxygen from the passing water supply, the underlying bacterial layers become dormant or die-off. This can possibly lead to the separation of upper layers of bacteria from the supporting media, which leads to biofouling. Excessive biofouling and increased solids buildup lead to mean cell residence time (MCRT) problems and a loss of hydraulic conductivity. In order to maintain hydraulic conductivity and avoid MCRT problems, the packed bead bed must be cleaned by backwashing. Period backwashing is essential to prevent clogging of the media bed. The media beds in SLDM filters are periodically expanded for removal of accumulated solids and excess biofilm (Malone and Beecher, 2000; Cooley, 1979). Backwashing or expansion of the bead bed can be accomplished by hydraulic, pneumatic or, mechanical means. Figure 1-3 illustrates the two modes of operation in a SLDM filter treating domestic wastewater using a pneumatic backwashing mechanism.

One drawback to granular medium filters, particularly with newer submerged biofilters, is the build up of headloss in the carrier material (Ødegaard *et al*, 1994). The head loss and caking problems associated with granular packed beds are minimized in SLDM filter applications using high-frequency backwashing. Increased head loss through the filter bed can cause biofouling and inhibit filter performance. A pneumatic backwashing technique used in SLDM filters effectively reduces bed and screen head loss thus permitting high-rate recirculation. During the filtration mode, air is introduced into an airtight "charge chamber" at a rate predetermined by the operator.

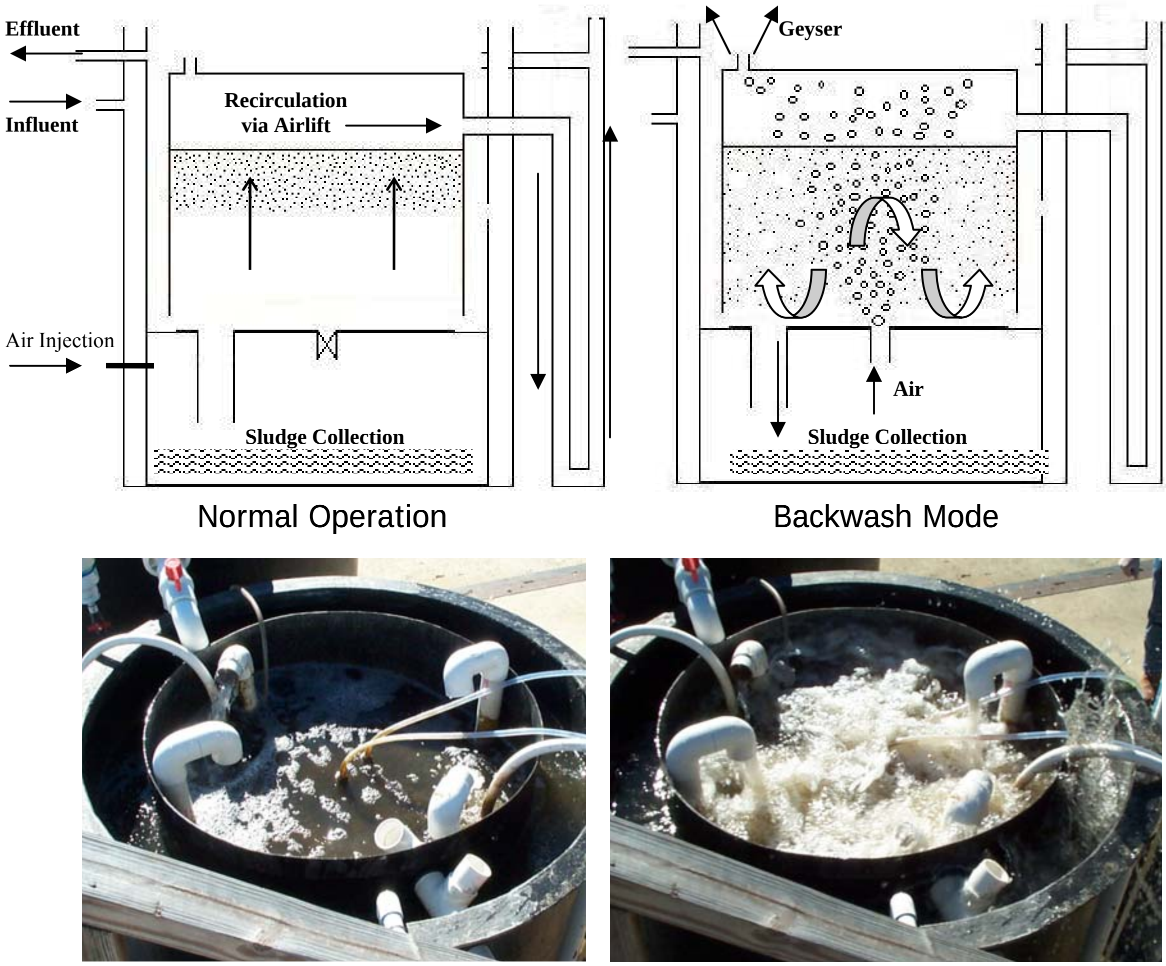


Figure 1-3. SLDM filters normally operate with a packed bed. The bed expands when a backwash occurs allowing excess biofloc to settle as sludge.

When the volume of air injected reaches the volume of the chamber, air is released into the bead bed agitating the media. The release of air abrades excess biofloc from the media surface and interstices of the bed. The volume of air displaced from the charge chamber is replaced by the backwash water causing a water level drop in the filter below the discharge level. During a backwash cycle, which usually lasts for less than two minutes, effluent is not discharged although wastewater application to the filter continues. Once the total volume of air is released from the charge chamber, the media floats upward and the bed returns to its static mode. As the air chamber is recharged, solids from backwash water settle. Displaced backwash waters and some residual solids are passed through the bead bed multiple times before effluent is discharged. Water loss is minimized to periods of accumulated sludge removal. Sludge is drained once or twice a week manually or can be automated.

Backwash frequency is the principal operational parameter used to enhance biofiltration performance. However, additional biofilm management flexibility is obtained by altering the bead shape. The selection of an appropriate medium is critical in the design and operation of SLDM filters where different media may be preferable for a specific SLDM application. Previous studies indicate that suspended solids removal increases with a decrease in size of individual media (Ahmed, 1996). The criteria for media selection in other treatment technologies, such as Biologically Aerated

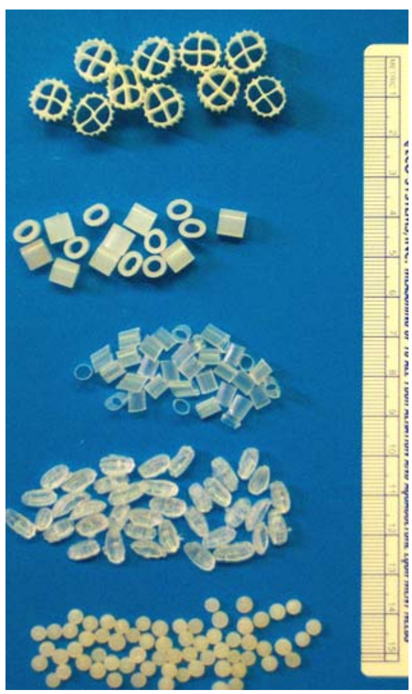


Figure 1-4. Various types of media have been tested in SLDM filters. From top to bottom: KMT, thick walled tubes, thin walled tubes, EN media, and spherical media.

Filters (BAF's), suggest using larger media for roughing applications and a smaller media for tertiary treatment (Moore et al., 2001). Two media, EN and KMT, were selected for evaluation of $CBOD_5$ and TSS removal in the following study. The Kaldness (KMT) media have proven effective for enhanced primary treatment of municipal wastewater at high filtration rates (Liao et al., 2002). Enhanced nitrification media have been used successfully in SLDM filters treating domestic wastewater in studies performed by Wagener (2003).

Static Low Density Media filters can be used throughout the treatment train as an effective means of reducing carbonaceous biochemical oxygen demand, total suspended solids, and total ammonia nitrogen from high and low strength domestic wastewaters. Strategic placement of the SLDM filter could simplify treatment processes by adhering to the consolidation strategy. The following study also investigated the use of SLDM filters for simultaneous removal of $CBOD_5$, TSS, and TAN from a moderate strength effluent of a primary clarifier in addition to a tertiary application for removal of TAN at low organic concentrations.

CHAPTER 2: CONCURRENT PHYSICAL AND BIOLOGICAL TREATMENT: THE INFLUENCE OF MEDIA CHARACTERISTICS IN STATIC LOW DENSITY MEDIA FILTERS

INTRODUCTION

Successful performance of filters and bioclarifiers is impacted by the physical characteristics of their media, such as specific surface area, porosity, shape, and specific gravity. Bioclarifiers must utilize floating plastic media with a high specific surface area (SSA m^2/m^3) and porosities to concurrently biologically and physically filter wastewater. The extensive surface area of the biofilm carriers support heterotrophic and with appropriate management, nitrifying bacteria. The granular filter bed captures large amounts of solids through straining, settling, interception, and adsorption on a single pass basis (Chen 1991).

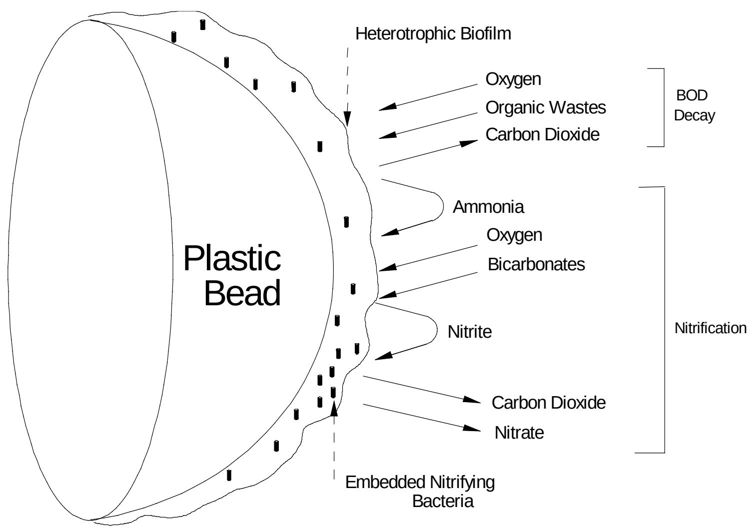


Figure 2-1. Representation of bacterial biofilm coating a granular plastic medium (Malone, 1995).

Media shapes and sizes have been shown to influence particulate capture. In a study performed by Deshpande *et al.* (2004) in which eleven commercially available media and four custom shaped media were evaluated, media that were smaller and spherically shaped were found to capture higher percentages of fine particulates than other sized and shaped media, when operated under similar conditions. The same study by Deshpande *et al*., (2004) revealed the presence of biofilm on the media as well as operation under lower fluxrates further increased the removal of particulates in all the tested size ranges. The physical effect of straining, settling, interception, and adsorption is furthered magnified in multiple pass systems due to the effect of increased solids buildup and biofilm formation.

The use of different media types in SLDM filters has been previously tested for aquacultural wastewaters where the improvement in nitrification capacity is the main objective (Sastry, 1995). It has been established in the literature that proper media selection and filtration rates will improve solids capture in granular medium filters (Deshpande *et al*., 2004). Results from extensive nitrification and solids removal studies employing SLDM filters in the aquaculture arena have given momentum to much needed media evaluations aiming to enhance bioclarification of domestic wastewater. It was therefore decided to carry out an experimental investigation comparing the ability of two granular biocarriers to produce secondary in addition to tertiary effluent quality using an airlift recirculating Static Low Density Media Filter.

The two media selected for this study have characteristics such as high specific surface area and porosity, densities less than that of water, and the ability to protect biofilm; this makes them desirable for SLDM filters operated in a high frequency washing mode. The Kaldness (KMT) bilofilm carriers allow operation under low headloss with larger screen openings making it attractive for use in an airlift environment.

The EN media has a higher specific surface area and was presumed to have superior solids capture attributes which may counterbalance advantages of the KMT media. The media were placed in two identical field units and tested under similar conditions.

BACKGROUND

In previous studies, involving recirculating aquacultural waters, total ammonia nitrogen conversion capacities for specific media have been documented (Sastry, 1996). TAN conversion capacities for standard spherical beads, EN (Enhanced Nitrification), and tubular media along with respective filter media characteristics can be seen in Table 2-1.

Table 2-1. Peak volumetric nitrification rates of three different media with representative characterisitcs at a fish feed loading rate of 2.04 kg/m3.day (Malone *et al*., 1993; Sastry, 1996; Stahl *et al*., 1996).

Media Type	*Specific Surface Area (m^2/m^3)*	*Porosity*	Volumetric Nitrification Rate ($gms/m^3.day$)
Standard Beads	1148	0.35	752
EN (Modified Beads)	1175	0.55	1015
Tubes	656	0.85	1190

In work performed by Sastry (1996) the nitrification capacity of standard spherical beads and tubular media were compared at different feed loadings. Sastry found that tubes performed better than beads at lower substrate concentrations. However, the tubes failed to support higher loadings beyond a feed rate of 16 $kg/m^3.day$ due to loss of specific surface area through clogging of the interior surface. Further studies involved modifying the shape of the spherical bead to allow for more biofilm protection (Stahl *et al*., 1996). Altering the bead shape, which created a boat-shaped media with the needed specific surface area for biofilm growth, while providing biofilm protection on the external surface. The modified bead, later named enhanced nitrification (EN) media, maintains a light biofilm layer that becomes thicker within the deeper depressions (Stahl *et al*. , 1996). The external nature of the protection, however, facilitates biofilm removal under the heaviest loading conditions.

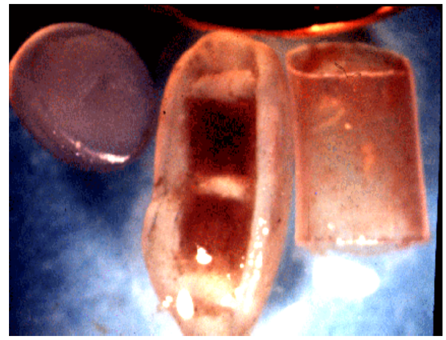


Figure 2-2. Various shapes of media have been used in SLDM filter applications. From left to right: standard beads, modified beads (EN), and tubes

Kaldness (KMT) media have been used extensively in Moving Bed Biofilm Reactors (MBBR's) in more than 300 plants around the world (Liao *et al*., 2002). These MBBR's have been applied for various treatment purposes such as BOD/COD removal, nitrification, and denitrification in both municipal and industrial wastewater (Odegaard *et al*., 2000). Moving Bed Biofilm Reactors use media of high specific surface area which move freely with the continuously mixed water in the reactor as shown in Figure 2-3.

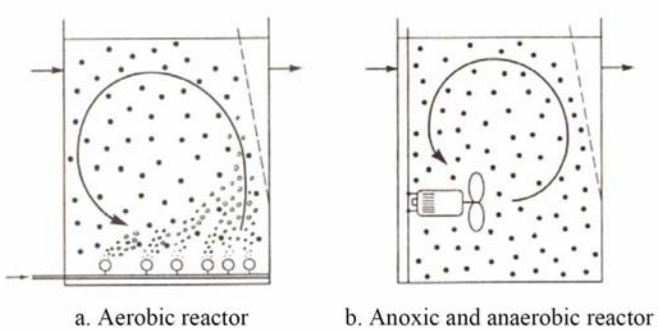


Figure 2-3. The Kaldnes (KMT) media have been used in moving bed biofilm processes. The low-density media move freely with the water in the reactor (Odegaard *et al*., 1994).

The Moving Bed Biofilm process has been used for many different applications. It was developed when nitrogen removal became in focus and most of the scientific data has been gathered from this application (Odegaard et al., 1994; Odegaard et al., 2000). More recent investigations have focused on organic matter removal using Moving Bed Biofilm Reactors employing the Kaldnes (KMT) carrier (Odegaard 1998; Liao et al., 2002).

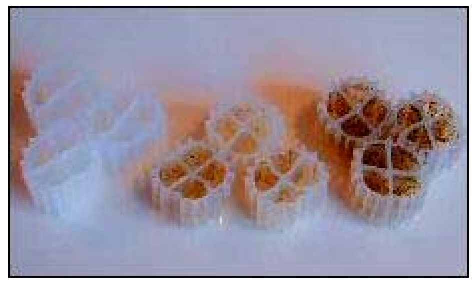


Figure 2-4. Kaldness biofilm carrier

The KMT media allow operation under low head loss avoiding sieve clogging problems associated with newer submerged biofilters while maintaining a good specific biofilm surface (500 m^2/m^3). The Kaldness biofilm carriers are shaped like small cylinders about 10 mm in diameter and in height (Odegaard *et al*., 1994). The spoked cylindrical shape provides excellent internal biofilm protection with a more moderate protection for external biofilm growth. This combination of properties makes KMT a good competitor with other media used in present and emerging submerged biofilter applications.

METHODOLOGY

Two pilot scale SLDM filters were simultaneously evaluated in parallel to determine the capacity for $CBOD_5$ and TSS removal. Both SLDM filters consisted of a 113.3L ($4ft^3$) media bed with a depth of 38 cm inside of an equalization tank. The configuration of both filters was exactly the same except for the media used. The P7a prototype was in operation from June 2002 to May 2003. The EN filter media used in the P7a filter was 3 to 5 mm in diameter, with a density of 0.90 kg/L, a porosity of 0.55, and with a total specific surface area of 1175 m^2/m^3 (Malone *et al*., 1993). The P7b prototype was in operation from August 2002 to May 2003. The P7b prototype contained a Kaldnes carrier media (KMT), which were 10 mm in diameter, with a density of 0.90 kg/L, a porosity of 0.75, and a total specific surface area of 550 m^2/m^3 (Odegaard *et al*., 2000).

Both experimental units had a total water volume of 1.78 m^3 with four separate compartments allowing simultaneous water exchange. The four compartments included an outer equalization tank (0.78 m^3), an inner polishing chamber (0.66 m^3), a filter bed (0.11 m^3), and a sludge collection chamber (0.23 m^3). A 3- inch airlift (PVC) was used to circulate water between the polishing chamber and the media bed.

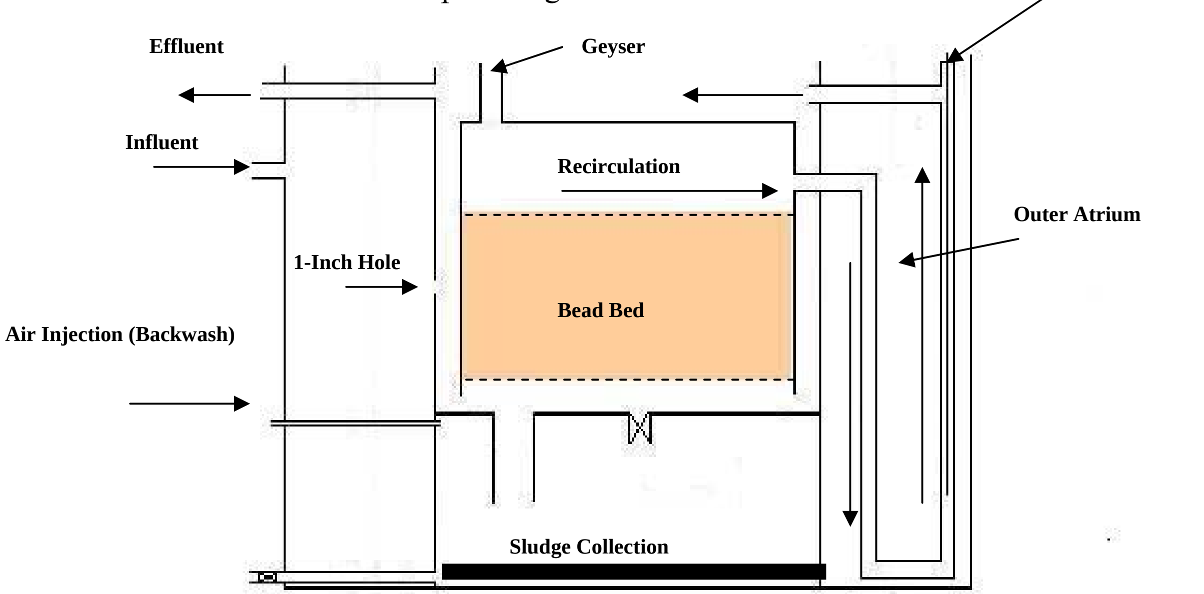


Figure 2-5. Diagrammatic representation of the experimental prototype systems used to simultaneously biologically and physically treat wastewater.

Water was allowed to pass through a one-inch hole from the outer atrium to the polishing chamber. A small amount of water was also backmixed via the same airlift back into the outer equalization tank. Backmixing prevented the outer tank from going completely anaerobic, leveled out loading peaks, and helped maintain the biofilter during the night. A pneumatic backwashing technique prevented effluent discharge immediately after backwashing trapping abraded biofloc in the sludge chamber. The backwash frequency was kept between 8-10 backwashes per day throughout the study period. The airlift system designed for the SLDM filters used in this study is shown in Figure 2-6.

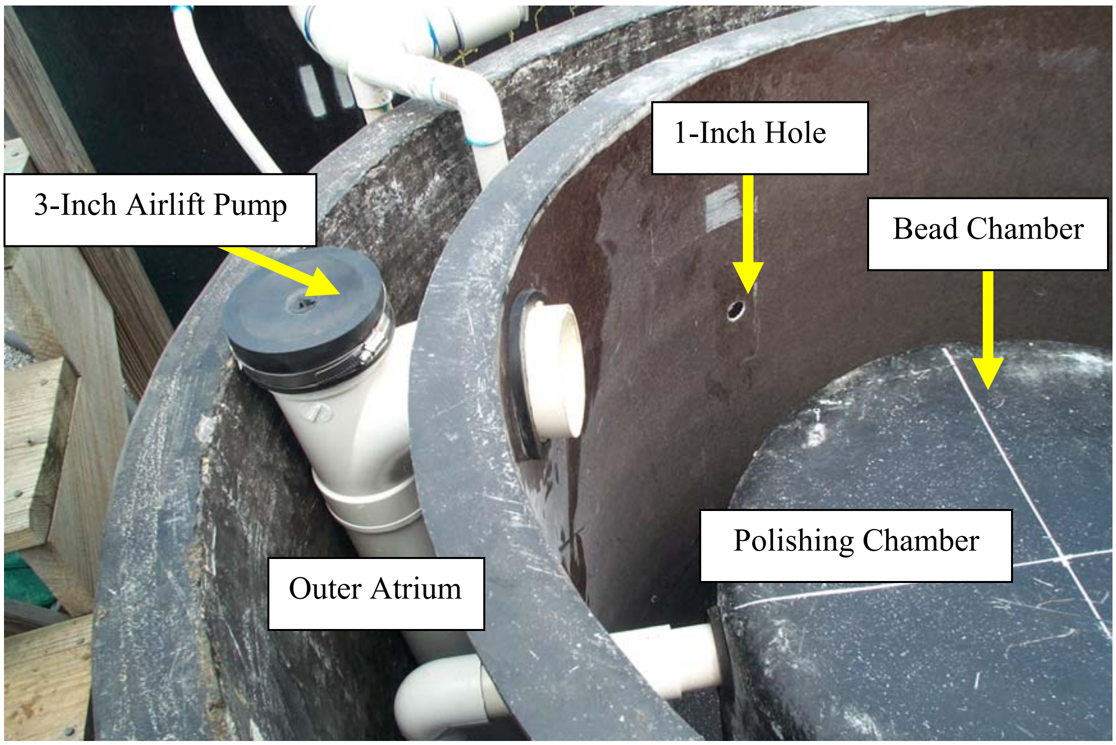


Figure 2-6. The P7 experimental units were equipped with a single 3-inch airlift pump. The airlift was placed in the outer atrium allowing greater submergence.

The filters were operated at an outdoor facility in Denham Springs, Louisiana, and received primary effluent domestic wastewater from a small commercial facility employing approximately 40 individuals. Due to the nature of the facility, the filters were subject to highly variable flow characterized by morning and afternoon peaks and no overnight flow. The wastewater was collected in an underground sump. The raw wastewater was pumped from the sump to a large tank that acted as a primary clarifier, and then flowed to the experimental units. The variations in flow from the facility were induced by the break schedule. Periodic large slugs of outflow from the clarifier were stabilized by the outer atrium chamber. Following the filter-tank combination was an effluent holding tank. This effluent tank contained a trash pump and was followed by a meter so that the total volume exiting through the system could be determined. The influent wastewater characteristics to the experimental unit can be seen in Table 2-2.

Table 2-2. The quality of the influent wastewater was the same for both filter prototypes**.**

Parameter	*Average Value*
$CBOD_5$, mg/L	103.6 ± 18.3
(n)	(15)
TSS, mg/L	77.4 ± 24.7
(n)	(16)
Temperature C	24.1 ± 4.7
(n)	(16)

The entire system was operated for more than one month in an acclimation mode prior to testing in order to ensure population and growth of a sufficient bacterial population. During this period wastewater was circulated through the filter; however the backwashing frequency was lowered so the bacteria could be established on the biofilm carrier.

Analytical Methods

Temperature, pH, and flow measurements were recorded along with other operational parameters, such as backwash frequency, during each sampling event. Water quality parameters were tested in triplicate according to Standard Methods for the

Examination of Water and Wastewater and include the following: $CBOD_5$ (5210B), DO (4500-O C), TSS (2540 D), and VSS (2540 E) (APHA, 1995).

RESULTS AND DISCUSSION

Operational Parameters

Operational parameters such as filtration rate and recirculation flow rate can greatly affect filter performance. Since SLDM filters incorporate high rate recirculation, the incoming wastewater is passed through the media bed many times before discharge. Recirculation flow rates in SLDM filters can be 60-70 times greater than total flow through the system. High rate internal recirculation in SLDM filters supports $CBOD_5$ and TSS removal through multiple passes as the airlift maintains aerobic conditions in the media bed. Residual oxygen levels of 0.5 to 2.0 mg/l are required to prevent oxygen limiting conditions (Davis and Cornwell, 1999). Oxygen limiting conditions were defined for this study to occur if the dissolved oxygen coming out of bead bed was less than 1 mg/l. As the filtration rate decreased in this study, the one pass retention time increased which resulted in a greater mass of oxygen consumed on that pass. The rate of oxygen utilization in SLDM filters is described as the OUR (oxygen uptake rate) and is calculated via the following equation:

$$OUR = \frac{(DO_{in} - DO_{out})Q_r}{V_b} \qquad \text{Equation 2.1}$$

Where DO is the dissolved oxygen concentration before and immediately after the bead bed in mg/l, Q_r is the recirculation flow rate through the bed in m^3/day, and V_b is the volume of filter media in m^3.

The oxygen uptake rate has proven to be an effective tool in the management of bead filters (Manthe et al., 1988). OUR is a measurement of the combined respiration of nitrifying and heterotrophic bacteria which extract soluble and particulate BOD from the bulk liquid (Malone et al., 2000). The mean oxygen uptake rate for the EN media was typically twice the value of the KMT media. Using statistical analysis, a significant difference in oxygen uptake rate was inferred between the EN and KMT media with a 95 percent confidence level. Operational parameters for the same experimental regimes described above can be found in Table 2-3.

Table 2-3. Operational parameters for both prototypes

Experimental Prototype	*Filtration Rate (m/h)*	*Retention Time (min)*		*Oxygen Uptake Rate (kg/m³.d)*
		One Pass	*Total*	
P7a (n)	15.7 ± 6.3 (15)	1.1 ± 0.6 (15)	90.7 ± 0.8 (15)	1.80 ± 0.5 (15)
P7b (n)	17.5 ± 7.6 (15)	0.73 ± 1.6 (15)	89.7 ± 1.3 (15)	0.93 ± 0.6 (15)

Fixed film reactors such as SLDM filters are capable of operating at much lower residence times than suspended growth reactors while providing equal substrate removal (Meunier and Williamson, 1981). The filtration rates of both medias were compared using a two sided t-test with a 95% confidence level and were found to be statistically similar. Filtration rates from 15 to 20 m/h for this study were comparable with other work employing floating media filtration (Liao *et al*., 2002). The filtration rates for this study were calculated using Equation 2.2.

Filtration Rate (m/h)= $\dfrac{Q_r}{\left(\dfrac{V_b}{d}\right)24}$ Equation 2.2

Where d is the depth of the bed in meters. The equations used to calculate retention time are shown below:

One Pass Retention Time (min) = $\dfrac{V_b * \varepsilon * 1440}{Q_r}$ Equation 2.3

Total Retention Time (min) = $\dfrac{V_b * \varepsilon * 1440}{Q}$ Equation 2.4

Where ε is the porosity, Q represents the total flow applied to the entire system in units of m^3/day, and 1440 was used to convert from units of days to units of minutes.

Recirculation flow rate through the bead bed becomes very critical when operating under aerobic conditions. The SLDM filters were operated as low head loss static bed biofilters, allowing the use of an airlift for water movement through the media matrix and providing external aeration. Filtration rate and residence time are impacted by head loss through the screens and media bed. Figure 2-7 illustrates the effect of increasing head loss on filtration rate through the bead bed. In the figure, the total head loss includes both top and bottom screens above and below the bead bed. The mean total headloss for the KMT and EN media beds during the course of the study was 3.0 and 7.0 cm, respectively.

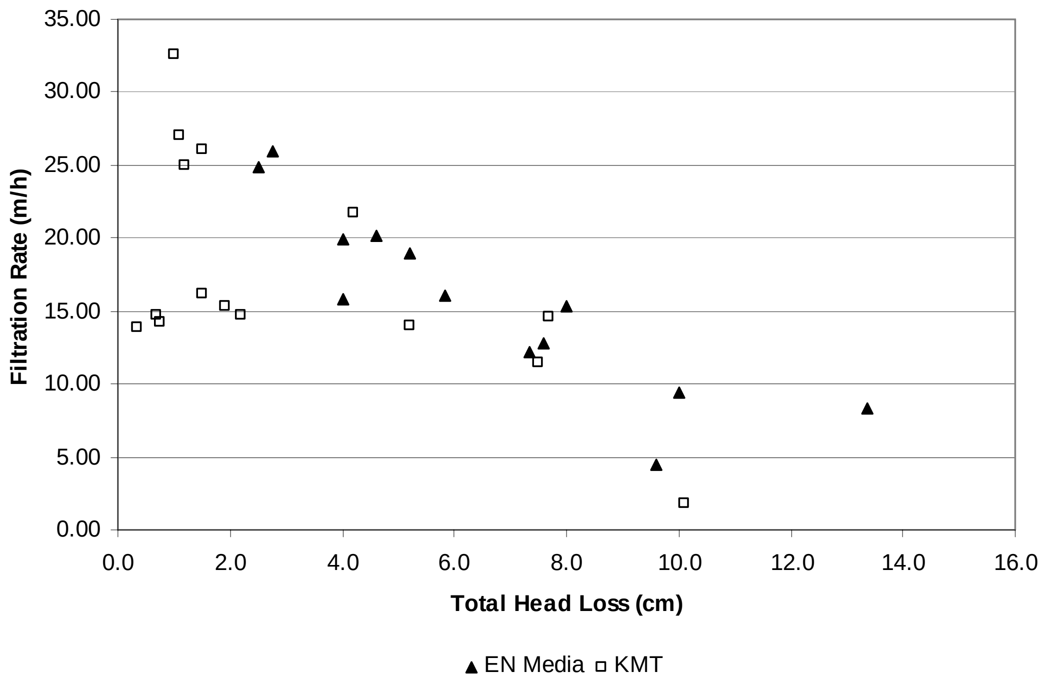


Figure 2-7. The filtration rate through the filter bed is slowly inhibited as head loss steadily accumulates until a backwash occurs restoring hydraulic conductivity.

$CBOD_5$ Removal and Organic Loading Characteristics

Experimental results for the P7 prototypes were divided into data sets for each media. The results from the reactor containing EN media show carbonaceous biochemical oxygen demand ($CBOD_5$) concentrations to decrease from 103 mg/L to 5 mg/L on average for this period. Total suspended solids (TSS) concentrations decreased from 77 mg/L to 7 mg/L on the average. The results from the prototype containing KMT media (the P7b data set) show $CBOD_5$ concentrations decreased from 103 mg/L to 19 mg/L on average. Mean TSS concentrations for P7b decreased from 77 mg/L to 19 mg/L. The results in this section were compiled from data collected for both prototyes from August to December 2002. Results for both prototypes can be found in Table 2-4.

Table 2-4. Results are for the entire system including the equalization basin and multiple passes through the media bed using an airlift for high rate recirculation.

Experimental Prototype	*$CBOD_5$ Influent = 103.6 mg/l*			*TSS Influent = 77.4 mg/l*		
	Total Load ($kg/m^3.d$)	Effluent (mg/L)	% Removal	Total Load ($kg/m^3.d$)	Effluent (mg/L)	% Removal
P7a (EN)	1.2 ± 0.4	6.2 ± 1.4	94.3 ± 2.3	0.8 ± 0.5	7.3 ± 7.4	87.2 ± 0.1
(n)	(15)	(12)	(12)	(13)	(13)	(13)
P7b (KMT)	1.6 ± 0.6	19.4 ± 9.9	82.9 ± 8.3	1.1 ± 0.6	18.9 ± 8.9	81.6 ± 0.1
(n)	(15)	(12)	(12)	(15)	(15)	(15)

$$Loading_{Total} = \frac{S * Q}{V_{bed}} \qquad \text{Equation 2.5}$$

Where S is the substrate concentration, $CBOD_5$ or TSS in mg/l, entering the filter bed.

In earlier studies employing SLDM filters treating domestic wastewater, the relationship between effluent $CBOD_5$ concentrations resulting from a corresponding applied load was explored (Wagener 2003). The performance data obtained from prototype 7 and previous units were used to evaluate the relationship between the organic loading and the effluent quality. This information is useful in design considerations, and it provides a basis for comparison of this filter with other SLDM Filter configurations and other treatment technologies. The loading curve to the entire system of prototype 7a along with earlier prototypes was developed and is shown below in Figure 2-8. The curve illustrates a range of organic loadings (i.e. $CBOD_5$ loadings) to the entire prototype (bead filter with multiple passes plus the equalization tank) per volume of media in the filter per day. This correlation between organic loading applied and effluent concentration was used to evaluate filter performance for both prototypes evaluated (Figure 2-8). For P7a (EN media), effluent concentrations below 10 mg/l were consistently achieved at applied organic loads up to 1.9 kg/m^3.day, respectively. For P7b (KMT media), the relationship between organic loading and effluent concentration was not correlated.

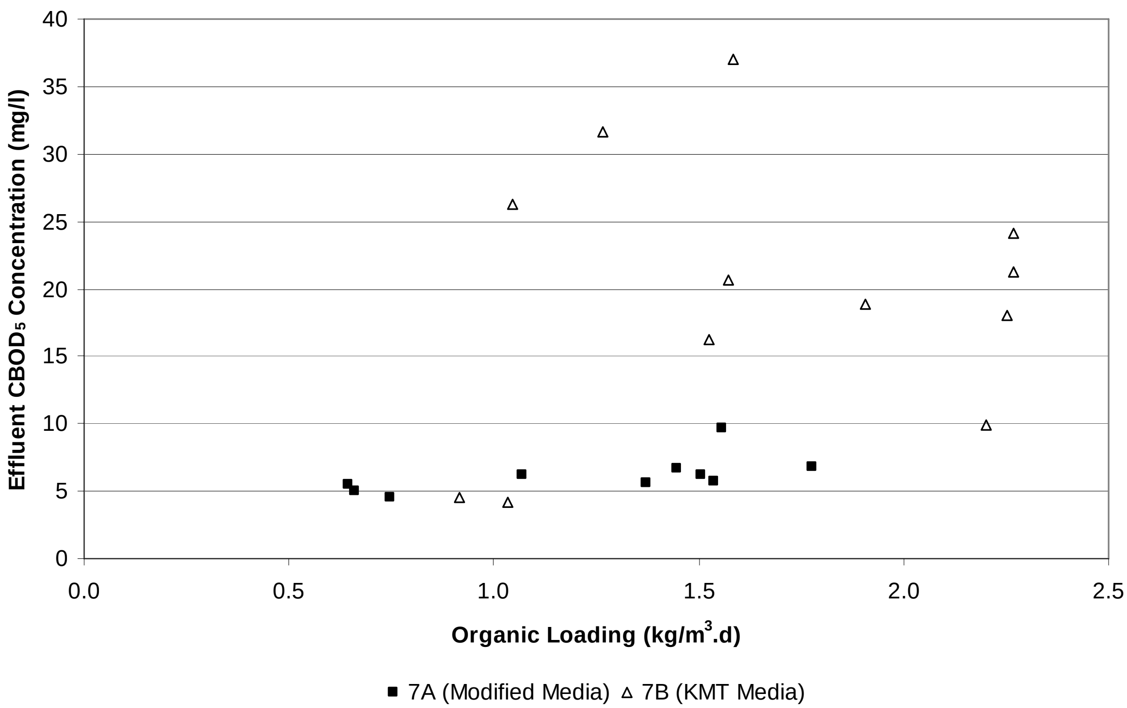


Figure 2-8. Effluent $CBOD_5$ concentrations remained below 10 mg/l at organic loadings up to 1.9 kg/m^3.day for EN media.

Total Suspended Solids Removal

In domestic wastewater, the largest portion of the organic matter is non-soluble (Larsen *et at*., 1994). Most of the pollutants in wastewater exist in particle or colloidal form or are transferred to this form in the course of the treatment process (Odegaard 1998). The removal of suspended solids was suspected to have an impact on the effluent $CBOD_5$ concentration exiting the bioclarifier. A higher TSS removal efficiency has shown to decrease effluent $CBOD_5$ concentrations in a study where the fraction of particulate bound $CBOD_5$ was found to increase from 0.37 to 0.73 as the wastewater traveled from the influent point until it exited the filter (Wagener 2003). In the same study by Wagener (2003), soluble $CBOD_5$ was consistently found to be less than 5 mg/l. Other researchers have found that particulate organics can interfere with removal of dissolved organics, particularly in biofilm processes (Sarner, 1986; Figueroa and Silverstein, 1990).

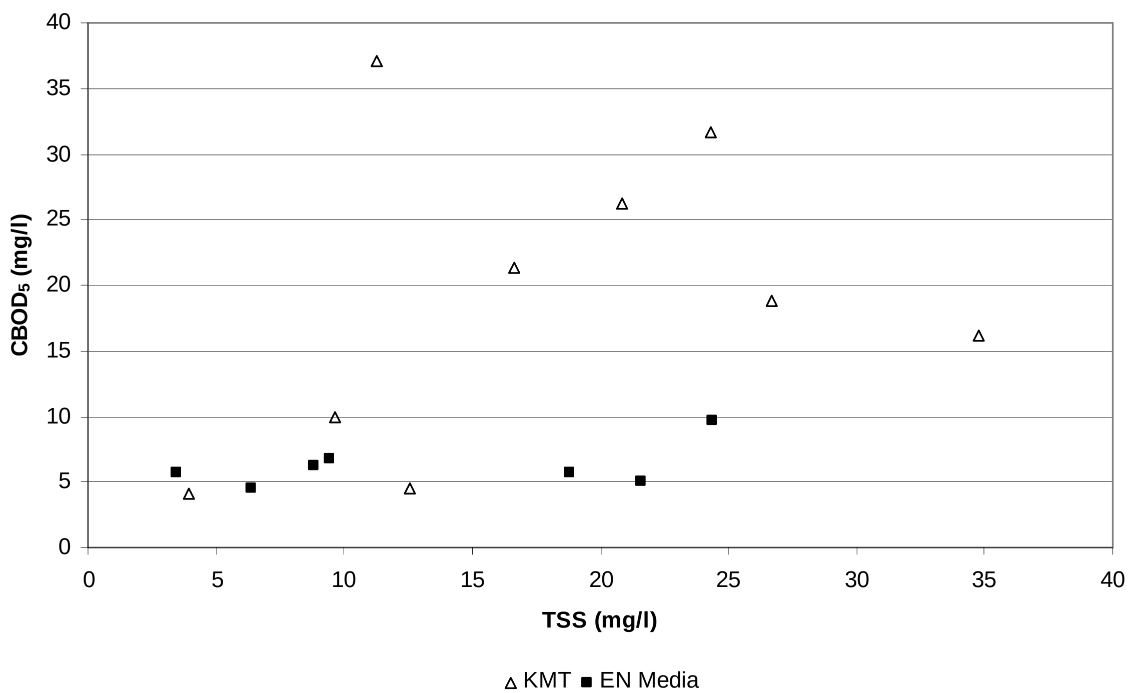


Figure 2-9. Total suspended solids contribute to elevated $CBOD_5$ levels in filter effluent.

Past partitioning studies have also suggested a strong relationship between $CBOD_5$ and total suspended solids in SLDM filter recirculating aquaculture applications (Malone *et. al,*. 1990). The relationship between effluent TSS and $CBOD_5$ for both media tested is shown in Figure 2-9.

Size and shape of floating media have been shown to impact the ability of filter beds subjected to similar operating conditions to capture particles of different size ranges. Previous studies in the aquaculture arena have shown that SLDM filters remove nearly 100% of particles larger than 50 μm on the first pass (Malone et al., 2002). Enhanced Nitrification and Kaldness media were evaluated along with other media types for removal efficiency of 5-10 and 20-50 micron sized particles on a single pass basis. (Despande *et al*., 2004). For single pass applications lowering the flowrate enhances removal efficiency, (Liao and Odegaard, 2002; Ahmed 1996); however, in recirculating systems the lowest TSS levels are obtained by maximizing the flowrate (Ahmed 1996). The study by Deshpande *et al* (2004) revealed that smaller media showed substantially improved capture of fine solids with better removal at lower fluxrates. With respect to fine solids capture and and media selection, effluent $CBOD_5$ concentrations below 10 mg/l were consistently achieved using this SLDM configuration with the small boat-shaped EN media.

The filtration rates for both experimental prototypes throughout the study were statistically similar as was the applied TSS loading to each unit. A time series graph of TSS removal for both media types can be seen in Figure 2-10. Effluent total suspended solids from the unit containing Enhanced nitrification media were significantly lower than that from the unit with KMT media. Future studies should use particle size analysis to determine the nature of the incoming solids load to determine the proper placement of the KMT unit within the treatment train.

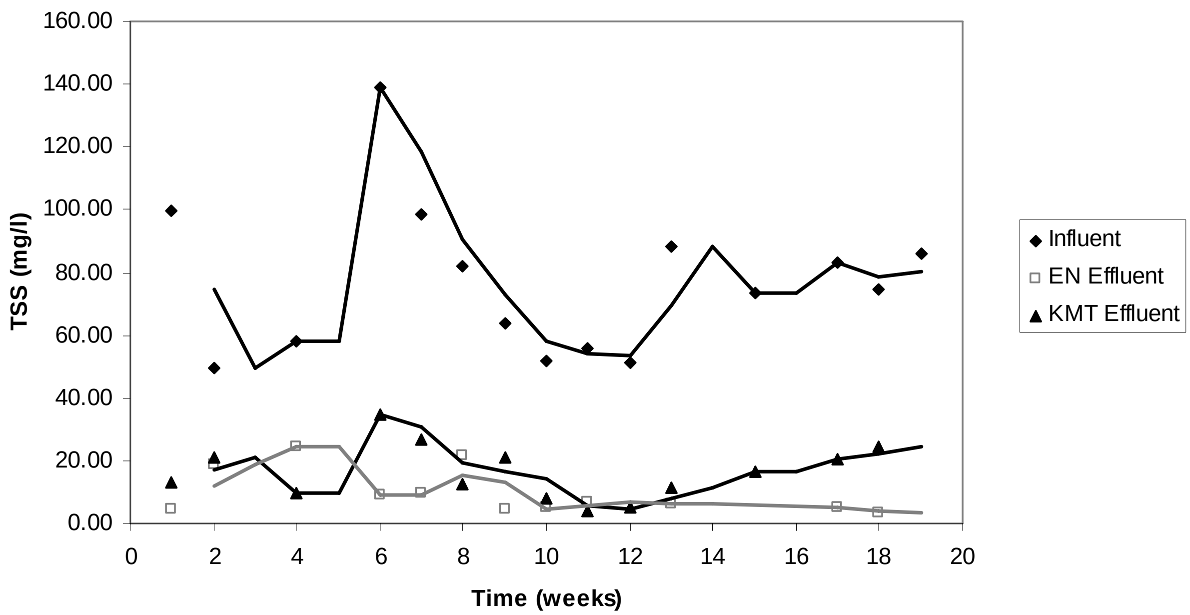


Figure 2-10. TSS Influent and Effluent Quality over Length of Study Period.

CONCLUSIONS

In the treatment of domestic wastewater, both biological and physical treatment must occur, and an increase in treatment capacity or use of more efficient operational strategies could result in significant savings and improve effluent water quality. The consolidation of biological and physical unit operations using SLDM (Static Low Density Media) filters has demonstrated the ability of a bioclarifier to effectively reduce $CBOD_5$ and TSS concentrations. Successful performance of the SLDM filters was impacted by the physical characteristics of their media, such as specific surface area, porosity, shape, and specific gravity. Biofilters may become smaller as the specific surface area of the filter media increases.

Sampling data indicated that a detectable clarifier performance difference can be accepted between the two media due to the statistical similarities in total suspended solids loading to each filter and filtration rate. Effluent TSS concentrations for the SLDM filter with EN media averaged 7.3 mg/l compared to the filter with KMT media at a significantly different 18.9 mg/l. The percentage of fine solids capture increases with multiple passes through the filter bed using an external airlift strategy. Effluent $CBOD_5$ concentrations below 10 mg/l were consistently achieved at an applied organic loading up to 2 kg/m^3.day using the smaller EN media.

The two media are comparable for solid liquid separation which can contribute to enhanced $CBOD_5$ removal. Although the advantages of the smaller matrix scale and superior surface area appeared to have supported the EN media in this comparison, the use of KMT media in the SLDM filter remained viable, possibly as a more robust roughing filter employed earlier in the treatment train. The results indicated that for a given reactor volume to produce a target effluent quality, media size can dictate the maximum loading rate with respect to solids capture.

CHAPTER 3: PRACTICAL APPLICATIONS OF STATIC LOW DENSITY MEDIA FILTERS FOR USE IN THE TREATMENT OF DOMESTIC WASTEWATER

INTRODUCTION

In response to increasingly strict regulations on effluent quality and other factors such as space and operational limitations, many existing domestic wastewater treatment systems require upgrades. Static low density media (SLDM) filters can provide a low cost, robust, and easily manageable treatment upgrade alternative. SLDM filters can be used to perform multiple duties by consolidation of unit operations into one single structure. The functions of biological treatment, secondary clarification, and tertiary treatment are accomplished in one bioclarifier. Previous studies have shown that both organic and solids removal can occur concurrently in a single Static Low Density Media (SLDM) filter, without the need for a secondary clarifier (Wagener *et al*., 2002). The small footprint required for placement of a SLDM filter makes it an easy addition to an existing treatment plant with minimal interference to the current treatment train. The SLDM bioclarifiers can operate with minimal supervision and require little maintenance. This paper investigates the practical uses of SLDM filters at two different locations in Louisiana each with unique wastewater characteristics. Each filter tested differed slightly in physical design but operated with an identical fundamental bioclarification treatment strategy. The focus was largely on $CBOD_5$, TSS, and TAN removal with attention given to greater fine solids capture to improve effluent quality.

Static Low Density Media Filters

Static low-density media (SLDM) filters are known in the aquaculture community as Floating Bead Filters (FBFs). The floating bead filters (FBF's) are expandable granular filters that display a bioclarification behavior similar to sand filters (Malone et al. 2000). The units are now widely employed as clarifiers or bioclarifiers in support of high-density recirculating production and holding systems for fish, reptiles, and crustacea (Malone and Beecher, 2000; DeLosReyes and Lawson, 1996).

The units are normally operated with the floating bed in a packed or static mode. In the packed bioclarification mode, the units concurrently provide solids capture, carbonaceous BOD removal, and nitrification. During the packed or filtration mode, influent wastewater enters below the media bed. At the end of each pass through the media bed, the water is returned to the polishing chamber 80 to 90 times before discharge. Recirculation with an airlift provides external aeration in addition to multiple pass removal of particulate and soluble $CBOD_5$ making it a very critical management tool with one pass retention times between 30 seconds to 1.5 minutes per pass.

The beds are periodically expanded for removal of accumulated solids and excess biofilm (Malone and Beecher, 2000; Cooley, 1979). Backwashing or expansion of the bead bed can be accomplished by hydraulic, pneumatic or, mechanical means. Figure 3-1 illustrates the two modes of operation in a SLDM filter treating domestic wastewater using a pneumatic backwashing mechanism.

One drawback to granular medium filters, particularly with newer submerged biofilters, is the build up of headloss in the carrier material (Ødegaard *et al*, 1994). The head loss and caking problems associated with granular packed beds are minimized in SLDM filter applications using high-frequency backwashing. Increased head loss through the filter bed can cause biofouling and inhibit filter performance. A pneumatic backwashing technique used in SLDM filters effectively reduces bed and screen head loss thus permitting high-rate recirculation via an airlift.

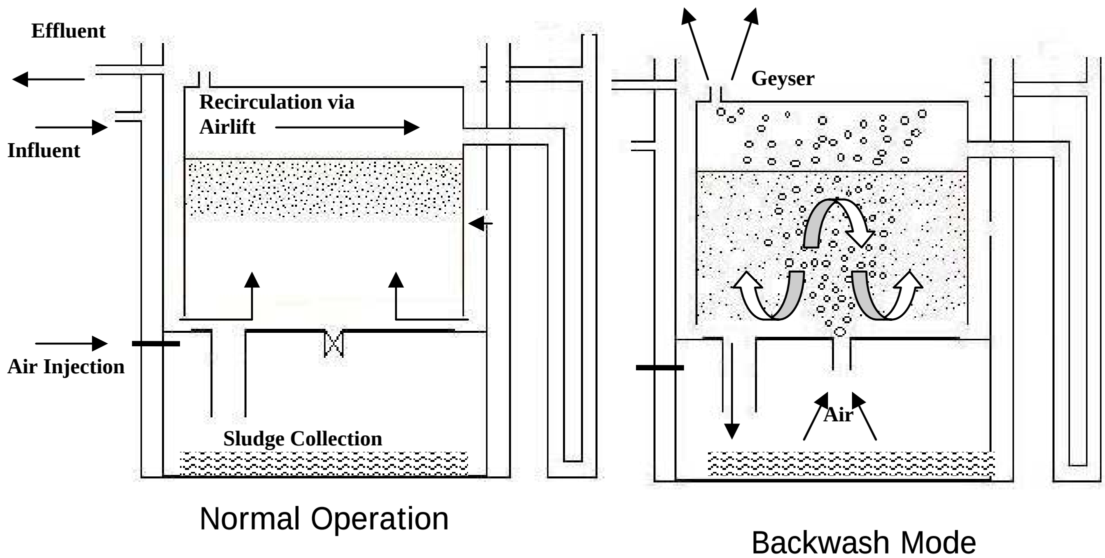
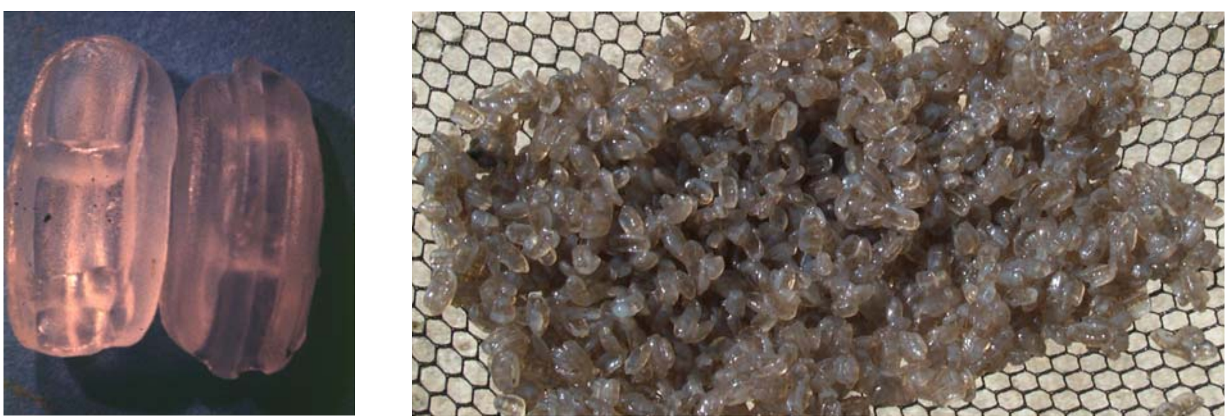


Figure 3-1. SLDM filters normally operate with a packed bed. The bed expands when a backwash occurs allowing excess biofloc to settle as sludge.

Air is introduced into an airtight "charge chamber" at a rate predetermined by the operator. When the volume of air injected reaches the volume of the chamber, air is released into the bead bed agitating the media. The release of air abrades excess biofloc from the media surface and interstices of the bed. The volume of air displaced from the charge chamber is replaced by the backwash water causing a water level drop in the filter below the discharge level. During a backwash cycle, which usually lasts for less than two minutes, effluent is not discharged although wastewater application to the filter continues. Once the total volume of air is released from the charge chamber, the media floats upward and the bed returns to its static mode. As the air chamber is recharged, solids from backwash water settle and are passed through the bead bed multiple times before effluent is discharged. Backwashing water loss is minimal and reduced to periods of sludge removal. Sludge is drained once or twice a week and can be automated or done manually. Additional biofilm management flexibility is obtained by altering the bead shape and the intensity of the backwash. An incorrect backwash rate, for example, can lead to deterioration in filter performance. However, some tolerance can be allowed in setting the filtration rates or media size without losing much in performance (Stevenson 1995). Once the unit is selected, backwash frequency is the principle operational parameter used to enhance biofiltration performance.

FIELD STUDIES

Each SLDM contained an Enhanced Nitrification (EN) media 3 to 5 mm in diameter, with a density of 0.90 kg/L, a porosity of 0.55, and with a total specific surface area of 1100 to 1250 m^2/m^3 (Malone *et al*., 1993). Backwash frequency was set at 8 -10



EN Media **Acclimated EN Media**

Figure 3-2. Enhanced nitrification media used in the pilot scale studies.

washes per day for every filter. These media display high hydraulic conductivity while providing biofilm protection during backwashing. Clean and acclimated EN (Enhanced Nitrification) and be seen in Figure 3-2. The media were acclimated for one month within each filter using the influent wastewater stream.

Analytical Methods

Temperature, pH, and flow measurements were recorded along with other operational parameters, such as backwash frequency, during each sampling event. Water quality parameters were tested in triplicate according to Standard Methods for the Examination of Water and Wastewater and include the following: $CBOD_5$ (5210B), DO (4500-O C), TSS (2540 D), and VSS (2540 E) (APHA, 1995).

Site #1: $CBOD_5$ and TSS Removal from the Primary Effluent of a Small Facility under Warm Water Conditions

An SLDM filter was operated at an outdoor facility in Denham Springs, Louisiana. The wastewater was characterized as primary effluent generated from a small commercial facility employing approximately 40 individuals. Due to the nature of the facility, the filters were subject to highly variable flow characterized by morning and afternoon peaks and no overnight flow. The raw wastewater entered a 2000 gallon (7.57 m^3) tank that acted as a primary clarifier, and then flowed to the SLDM unit. The experimental SLDM unit had a total water volume of 1.78 m^3. The resulting effect of this design was a dynamic system with four separate compartments allowing simultaneous water exchange. The four compartments included an outer equalization tank (0.78 m^3), an inner polishing chamber (0.66 m^3), a filter bed (0.11 m^3), and a sludge collection chamber (0.23 m^3). During the packed or filtration mode, influent wastewater entered an outer atrium chamber which served to equalize the incoming wastewater flow. The water then passed through a small opening to an inner polishing chamber and entered below the media bed. A 3- inch airlift was used to circulate water between the polishing chamber and the media bed. At the end of each pass through the media bed, the water was returned to the polishing chamber 80 to 90 times before discharge. Recirculation and external aeration was accomplished using airlift pumps achieving multiple pass removal with one pass retention times between 30 seconds to 1.5 minutes per pass.

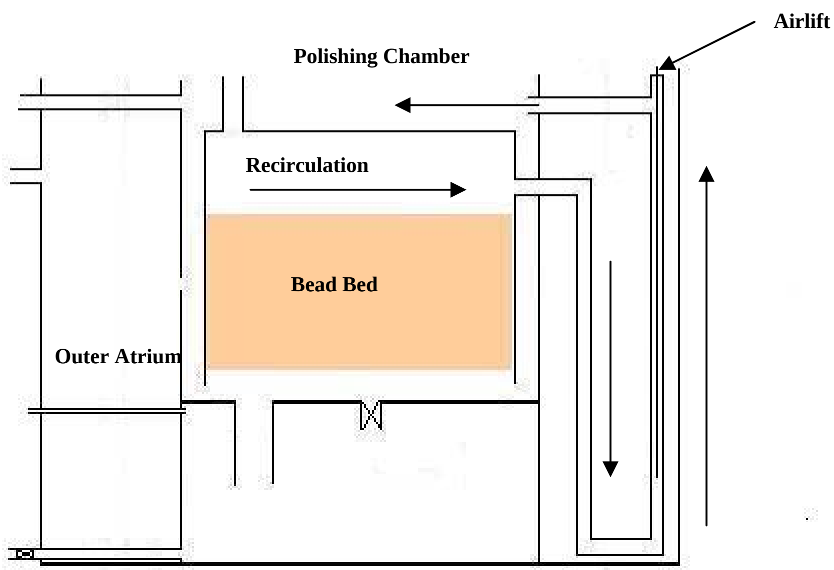


Figure 3-3. System schematic of prototype used showing airlift application and recirculation allowing multiple pass removal of $CBOD_5$ and TSS within the polishing chamber.

Due to the dynamic nature of the incoming flow stream, the outer equalization tank acted as a flow buffer before water entered the polishing chamber. A pneumatic backwashing technique prevented effluent discharge immediately after backwashing allowing abraded biofloc to settle into the sludge chamber. The experimental unit was operated at ambient conditions, while operational parameters such as backwash frequency, filtration rate, and total daily flow were controlled. The influent waste stream was characterized as warm water with an average temperature of 29.6 degrees celcius as shown in Table 3-1.

Table 3-1: Mean influent wastewater characteristics

Parameter	Average Value
$CBOD_5$, mg/L	96.9 ± 22.1
(n)	(15)
TSS, mg/L	55.5 ± 20.0
(n)	(15)
Temperature °C	29.6 ± 0.8
(n)	(15)

The laboratory results have shown carbonaceous biochemical oxygen demand ($CBOD_5$) concentrations to decrease from 96.9 mg/l to 5.5 mg/l on average. Average organic loading applied to the media bed of the entire system ranged from 1-2 kg/m^3.day. Total suspended solids concentrations decreased from 56 mg/l to 5.2 mg/l on average

Table 3-2. The average loading rate, effluent concentration, and percent removal results were based on the entire system including the filter and equalization basin.

	$CBOD_5$			**TSS**	
Total Load (kg/m^3.d)	**Effluent (mg/L)**	**% Removal**	**Total Load (kg/m^3.d)**	**Effluent (mg/L)**	**% Removal**
1.3 ± 0.3	5.5 ± 1.9	94.7 ± 0.02	0.7 ± 0.2	5.2 ± 2.1	88.7 ± 0.07
(14)	(14)	(14)	(14)	(14)	(14)

throughout the study period. The total loading rates in Table 3-2 were based on applied loading to the media bed and calculated from the following general equation:

$$Loading_{Total} = \frac{S * Q}{V_{bed}} \qquad \text{Equation 3.1}$$

The experimental unit showed steady performance for $CBOD_5$ removal in the presence of a variable applied organic load to the system which can be seen in Figure 3-4. In domestic wastewater, the largest portion of the organic matter is non-soluble (Larsen *et at*., 1994). Furthermore in SLDM filters, effluent $CBOD_5$ concentrations were found to be controlled by TSS indicating the importance of particle capture (Wagener 2002).

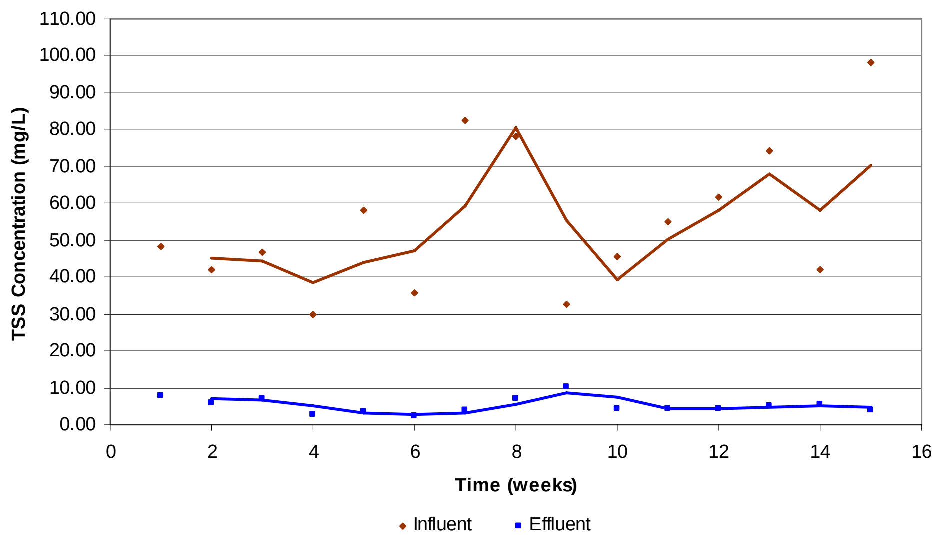


Figure 3-4. Effluent $CBOD_5$ concentrations remained below 10 mg/l throughout the study period.

Previous studies in the aquaculture arena have shown that SLDM filters remove nearly 100% of particles larger than 50 µm on the first pass (Malone et al., 2002). Particle removal efficiency increases with multiple passes through the filter bed using an external airlift strategy. Also, size and shape of floating media have been shown to impact the ability of filter beds subjected to similar operating conditions to capture particles of different size ranges (Deshpande *et al*., 2004). In the same study performed by Deshpande *et al*. (2004) in which eleven commercially available media and four custom shaped media were evaluated, media that were smaller and spherically shaped were found to capture higher percentages of fine particulates than other sized and shaped media, when operated under similar conditions. With respect to fine solids capture and media selection, effluent $CBOD_5$ concentrations below 10 mg/l were consistently achieved using this SLDM configuration with the small boat-shaped EN media.

The performance data obtained from the experimental prototype was used to evaluate the relationship between the organic loading and effluent quality. This information is useful in design considerations, and it provides a basis for comparison of this filter with other SLDM Filter configurations and other treatment technologies. The loading curve to the entire system was developed and is shown below in Figure 3-5.

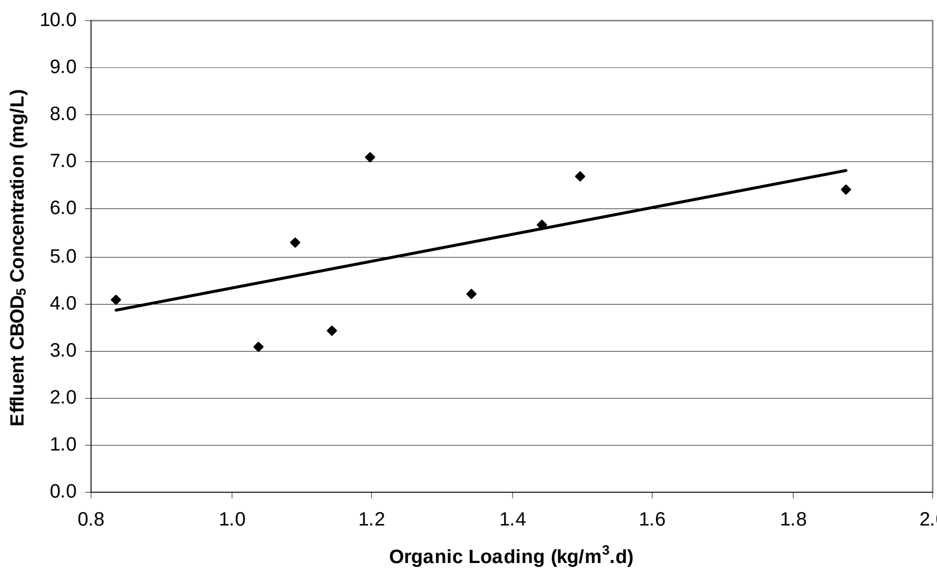


Figure 3-5: The relationship between organic loading and effluent quality can serve as a basis for comparison against other treatment technologies

The curve illustrates a range of organic loadings (i.e. $CBOD_5$ loadings) applied to the media bed per volume of media in the filter per day. Effluent $CBOD_5$ concentrations under 10 mg/l were consistently achieved at organic loadings up to 2 kg/m^3.day.

Site #2: Evaluation of SLDM Bioclarifiers as a Treatment Aid for an Interstate Rest Area

Interstate highways are long corridors connecting points of population such as small towns or major metropolitan areas. Rest areas are located at remote sites along these highway systems. Therefore wastewater treatment is largely decentralized due to the absence of sanitary sewer systems and many amenities facilitated by populated communities.

Three different SLDM filter applications were evaluated at an interstate rest area on I-49 near Grand Prairie, Louisiana, located approximately 60 km (40 miles) north of Lafayette. The treatment plant received flow from the main rest area building restrooms and a recreational vehicle (RV) dump station. The mean daily waste flow for this location was 19.62 m^3/day (3.6 gal/min) with 95 % of the total daily flow under 54.5 m^3/day (10 gal/min). The secondary treatment of wastewater at this facility was accomplished by subsurface flow rock filtration (Griffin *et al*., 1999). There were four rock filters, called cells, having dimensions of 45.7 m (150 ft) by 9.1 m (30 ft) with a mean depth of 0.6 m (2 ft). A schematic of the treatment process including septic tanks, rock filter cells, and chlorination station can be seen in Figure 3-6. Wastewater generated at the facility drained by gravity to an eductor (pump) station where it was airlifted to a channel containing a bar rack for screening of large objects. Waste strength at the eductor station averaged 750 – 1000 mg/l $CBOD_5$ and TSS and 30 mg/l ammonia. The wastewater then flowed into two 37.9 m^3 (10,000 gal) septic tanks connected in series with a hydraulic detention time of 2 days. A splitter box served as a sump to receive flow from the septic tanks and distribute flow to cells 3 and 1 which then flowed to cells 4 and

2. Effluent from cells 4 and 2 were then chlorinated before discharge was pumped into Lake Dubisson.

There were two testing positions within the treatment train where SLDM filters were applied. The first evaluation involved the use an internal recirculating SLDM filter for nitrification of total ammonia nitrogen generated within the rock filter in cell 2. The location of this unit used for nitrification is noted by the letter “A” in Figure 3-6.

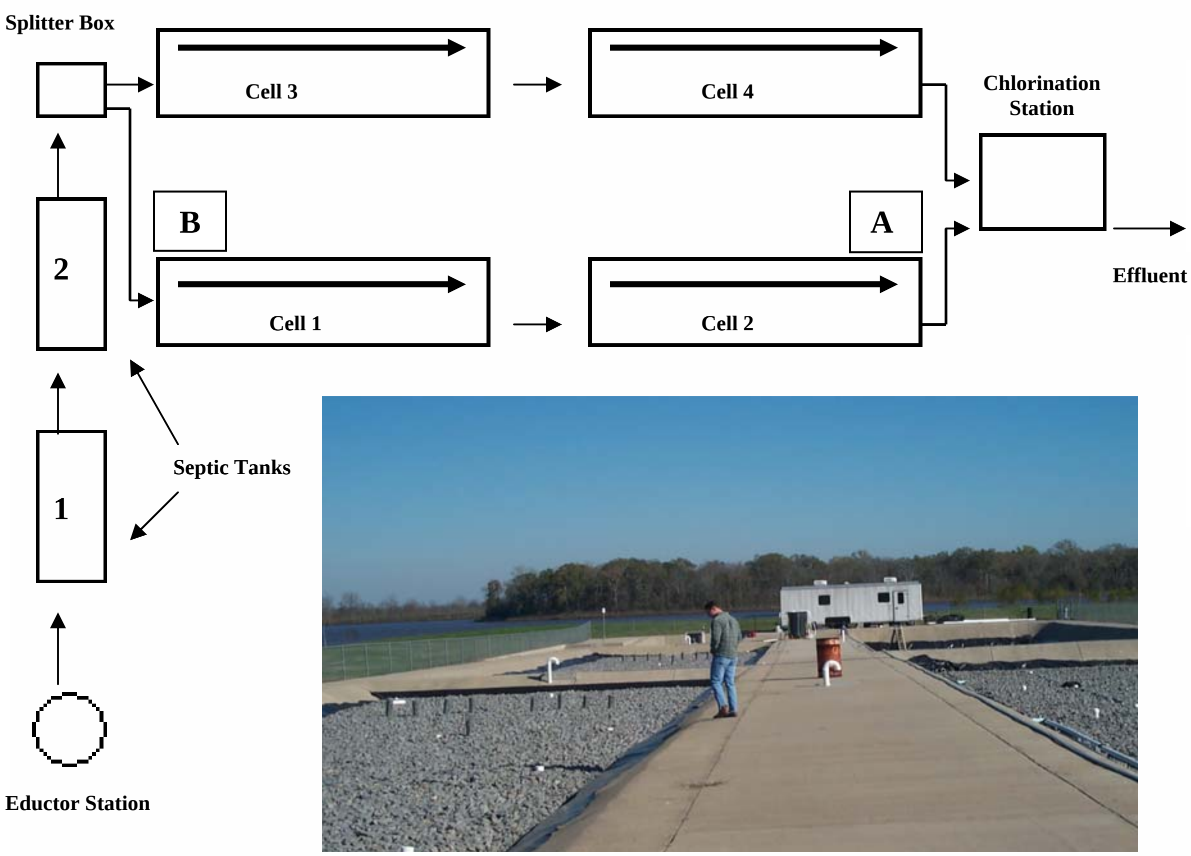


Figure 3-6. Schematic of Grand Prairie rest area top view and illustration looking down between the rock filter cell structures.

The following evaluation investigated the use two different SLDM unit configurations placed after primary clarification illustrated by location “B” in Figure 3-6. The SLDM units placed at location “B” within the treatment train were evaluated for their ability to function as a sole treatment device for $CBOD_5$ and TSS reduction in addition to nitrification in an organically rich environment.

The control of nitrogenous compounds in domestic wastewater has become important due to harmful and undesirable environmental impacts. Factors such as fish kills resulting from oxygen depletion due to nitrification in the receiving water body have led to a necessity to reduce the release of ammonia nitrogen from wastewater treatment facilities. SLDM filters have been successfully used for nitrification in recirculating aquaculture systems. Reactor volumes needed for nitrification can be four times larger than what is needed for carbon removal (Chandravathanam et al., 1999). The advantage of high specific surface area, an intensely aerated environment using airlifts for multiple pass removal of TSS, $CBOD_5$, and TAN, and enhanced backwashing techniques make these granular bioclarifiers an attractive upgrade to existing wastewater treatment facilities. Appling SLDM filters to the existing technology can improve treatment capacity especially where operational and space limitations favor more robust smaller volume reactors.

Total Ammonia Nitrogen Removal From Rock Plant Effluent

The first phase of experimental evaluation at the Grand Prairie interstate rest area involved the use of a SLDM filter for tertiary polishing of NH_3 in the effluent of a subsurface flow rock filter. Placement of the filter, shown in Figure 3-6 as location "A", was after the rock filter located in cell 2. The experimental unit consisted of a bead filter inside of an equalization / recirculation tank. The system was in operation from December 2001 until September 2002. The bead filter was two feet in diameter and contained 113.3L (4 ft^3) of buoyant plastic media, with a bed depth of approximately 38 cm. The carrier was a modified media 3 to 5 mm in diameter, with a density of 0.90 kg/L, a porosity of 0.55, and with a total specific surface area of 1100 to 1250 m^2/m^3 (Malone *et al*., 1993). The unit had a total water volume of approximately 1.78 m^3 (470 gallons). The bead filter was placed in the tank with a partition three feet in diameter separating it from the outer hull. The entire unit consisted of three chambers: an outer atrium, an inner polishing chamber, and a bead filter within the inner chamber. Openings below the bottom screen of the bead bed allowed water to move from the outer atrium to the inner chamber. Airlift pumps were used to circulate water from the top of the filter bed to the water surface in the inner polishing chamber. Although only one airlift is illustrated in Figure 3-7, two 2-inch airlifts located on a single axis that traversed through the center of the filter were used.

The total flow applied to the unit was 5.5 m^3/day (1 gal/min) throughout the study period. Other operational parameters such as backwash frequency, pH, and dissolved oxygen were also recorded. The system was operated for a one-month acclimation period

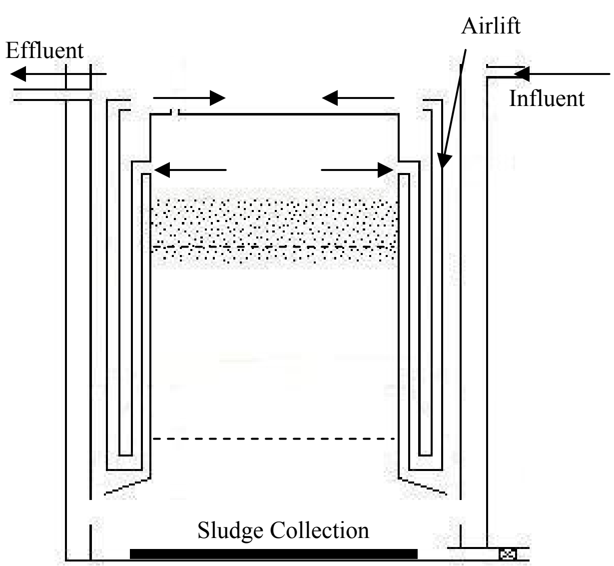


Figure 3-7. Recirculation and aeration was accomplished using an internal airlift strategy in the SLDM unit used for nitrification of rock filter effluent.

before testing began. The influent wastewater was characterized by a total ammonia nitrogen concentration averaging 64.1 mg/l and $CBOD_5$ and TSS levels under 10 mg/l.

Table 3-3. Influent Wastewater Characteristics

Parameter	Mean Value
Total Ammonia Nitrogen (mg/l) (n)	64.1 (6)
Dissolved Oxygen (mg/l) (n)	3.79 (6)
Total Suspended Solids (mg/l) (n)	11.0 (6)
$CBOD_5$ (mg/l) (n)	8.06 (6)

Results for the SLDM filter placed at end of rock filter show effluent total ammonia nitrogen levels at 8.68 and 55.38 mg/l on average under low and high substrate conditions based on TAN loading to the media bed. Percent TAN removal decreased from 82.3% for low substrate loading to 44.82 % for high loading. Low loadings applied were considered below 3.0 kg TAN / m^3.day.

Table 3-4. Average results from SLDM prototype used for nitrification

	TAN Loading (kg TAN / m^3.day)	Effluent TAN (mg/l)	Volumetric TAN Conversion (kg TAN / m^3.day)	Percent TAN Removal
Low Substrate (n)	2.1 ± 0.05 (8)	8.68 ± 10.8 (8)	1.69 ± 0.44 (8)	82.32 ± 20.8 (8)
High Substrate (n)	4.2 ± 0.08 (7)	55.38 ± 30.9 (7)	1.55 ± 0.83 (7)	44.82 ± 25.7 (7)

Total Ammonia Nitrogen Loading to the media bed in the SLDM system was calculated using Equation 2-1 with TAN as the substrate. The volumetric TAN conversion rate was calculated using Equation 3.2.

$$VTR = \frac{(TAN_{in} - TAN_{out})Q_r}{V_b} \qquad \text{Equation 3.2}$$

Where TAN_{in} and TAN_{out} are the concentrations of total ammonia nitrogen entering and exiting the entire system in mg/l, respectively.

The nitrification rate did not benefit from an increase in TAN loading to the system and was assumed a zero order reaction. Using a two sided t-test with a 95 % confidence level, a significant difference between TAN conversion capacities for low and high substrate loading could not be found. An average nitrification rate of 1.62 kg / m^3.day was achieved at mean effluent $CBOD_5$ levels ranging from 9-11 mg/l and TSS levels from 7-9 mg/l.

A relationship between TAN loading to the system and effluent concentration was found allowing effluent TAN values corresponding to an applied load to be determined. Effluent values below 10 mg/l were achieved at applied loadings up to 2.2 kg/m^3.day.

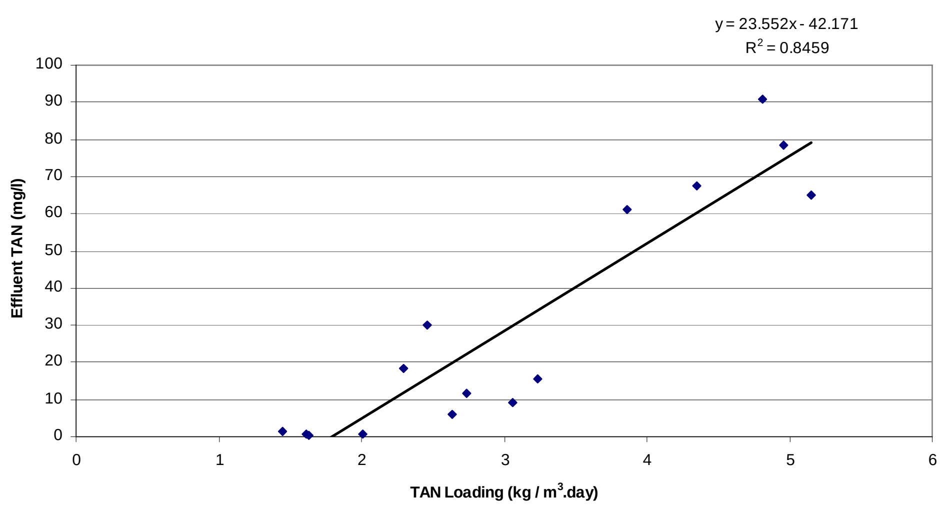


Figure 3-8. Effluent TAN concentration was linearly correlated with TAN loading in an effort to develop future design criteria.

Extended Aeration Followed by Static Low Density Media Filter

The second phase of experimental evaluation involved the use of a 2000-gallon extended aeration tank followed by a SLDM filter placed before the rock filter. This combination was applied for use as sole treatment of BOD, TSS, and TAN.
The objective was to increase the carrying capacity of the SLDM filter by reducing the organic load with the aid of an extended air holding tank used as a roughing filter. This system was operational from December 2002 until August 2003. The unit was fed primary effluent from the first septic tank. Circulation and aeration was accomplished by four 3-inch airlifts suspended in the center of the aeration tank. The wastewater was moved via airlift from the bottom center of the tank to the upper perimeter. In the center of the tank was a cylindrical clarifier suspended by cables along with the airlift structure. A 1-inch pipe was used to discharge wastewater from the top of the clarifier to the SLDM filter.

The SLDM filter used had a total capacity of 1.78 m^3. The filter consisted of three compartments: a polishing chamber 0.66 m^3 (174 gal), a bead bed 0.11 m^3 (30 gal), and a sludge collection chamber 0.23 m^3 (60 gal). A 3-inch external airlift was used to internally circulate water between the polishing chamber and the bead bed. This unit was similar in design to an earlier prototype discussed in chapter 2 but without the outer atrium. The experimental unit configuration can be seen in Figure 3-9. The system was dosed at a constant flow of 7.1 m^3/day (1.3 gal/min) and kept constant using an inline flow meter fed by a sump submersed in the second septic tank. Samples were taken at four points in the system, which were influent to the entire system, mixed liquor / suspended solids in the extended aeration unit, and influent and effluent to and from

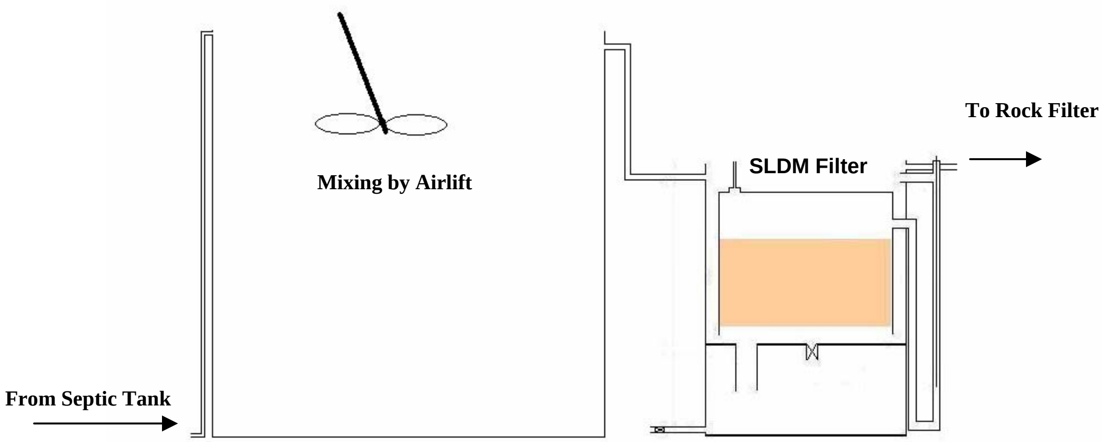


Figure 3-9. The extended air tank was equipped with an airlift system to ensure complete mixing and was followed by an airlift recirculating SLDM bioclarifier.

the SLDM filter. The effluent from the system was then discharged to the splitter box preceding the rock filtration structure. The influent wastewater characteristics to the entire system can be seen in Table 3-5.

Table 3-5. Influent Wastewater Characteristics From Primary Clarifier

Parameter	*Mean Value*
Total Ammonia Nitrogen (mg/l)	109.4 ± 24.1
(n)	(7)
$CBOD_5$ (mg/l)	202.1 ± 44.9
(n)	(8)
Total Suspended Solids (mg/l)	111.0 ± 24.5
(n)	(7)
Temperature	18 °C
(n)	(7)

Results from this study show a total average 77 percent reduction in $CBOD_5$ levels for the entire extended aeration / SLDM filter combination. SLDM filter performance was hampered by organic overloading at 3.6 kg $CBOD_5/m^3$.day in addition to excess total suspended solids discharged from the extended air unit resulting in elevated $CBOD_5$ concentrations in filter effluent. In comparison with other fixed film wastewater treatment units, effluent quality between 70 and 90 g $BOD_{Soluble}/m^3$ was achieved at soluble loading rates between 3.45 and 3.60 kg BOD_S/m^3.day (Harrison J.R. *et at*., 1987). Total suspended solids loadings applied to the SLDM unit were over 6 kg/m^3.day, indicating an overloaded filter with respect to suspended solids for this size SLDM filter. The suspended solids overshoot effect described by Wagener (2003) in addition to the SLDM filter being organically overloaded at 3.6 kg $CBOD_5/m^3$.day was suspected to have had an impact on organic removal. The availability of organic matter can stimulate the growth of heterotrophic bacteria, which compete with nitrifiers for limited available oxygen and space within the biofilm. Nitrification was suppressed in this study at 0.5 kg/m^3.day (12.9 g/ft^3.day) at effluent $CBOD_5$ concentrations in the range of 40 – 60 mg/l. Heterotrophic interference has been shown to impair both TAN and

Table 3-6. Average Results for Extended Aeration / SLDM Filter Combination

	$CBOD_5$	TSS	TAN*
Effluent From Extended Aeration Unit (mg/l) (n)	57.2 ±19.23 (7)	104.7 ± 35.09 (7)	43.6 ± 24.46 (7)
Total Load to SLDM filter (kg/m^3.day) (n)	3.63 ± 1.26 (7)	6.66 ± 2.23 (7)	2.7 ± 1.53 (7)
Filter Effluent (mg/l) (n)	45.4 ± 12.64 (8)	88.5 ± 31.69 (6)	36.3 ± 24.09 (7)
% Filter Removal (n)	30.8 ± 14.22 (6)	20.4 ± 10.17 (5)	21.8 ± 12.90 (7)
% Total Removal	77.0 ± 6.89 (8)	37.3 ± 17.1 (5)	63.7 ± 28.3 (7)

* Mean SLDM Filter Volumetric TAN Conversion = 0.45 kg/m^3.day ± 0.2

nitrite conversion (Zhang and Bishop, 1994). Also, in a study performed by Odegaard (1994), nitrification rates were retarded by the presence of organic matter at loadings over 3 kg COD/m^3.day (1.5 kg BOD_5 assuming BOD_5 = 0.5 COD) in moving bed biofilm reactors. Average ambient temperature in the system was 18° C. In a study where municipal sewage was treated with an upflow biofilter containing floating media, nitrification was not sensitive to temperatures greater than 14° C (M. Payraudeau *et al.*, 2000). Average results for the entire system can be seen in Table 3-6.

<u>High Rate Recirculation with SLDM Filter</u>

Two SLDM filter units were used in sequence for the sole treatment of TSS, BOD, and TAN at the upper end of the plant preceding the rock filters. This study involved the use of a high-rate recirculating SLDM filter connected to a 1.89 m^3 (500 gal) recirculation tank followed by another smaller SLDM unit. Both of these filters were automatic pneumatically washing units requiring little supervision. The purpose of this design was to remove the gross amount of BOD and TSS with the first SLDM filter and recirculation basin combination, and the second SLDM filter was to capture any fine solids exiting the first system in addition to supplemental soluble $CBOD_5$ removal operating at a much lower filtration rate on a single pass through the filter bed. This was the final experimental unit tested the Grand Prairie rest area and was in operation from November 2003 to May 2004. The first SLDM had a total capacity of 3.6 m^3 (950 gal) with a 0.23 m^3 (8 ft^3) bead bed. A 4-inch external airlift was used to move water between the tank and the SLDM filter creating a recirculating configuration. Enhanced Nitrification media was used in this application. The second SLDM filter contained 0.14 m^3 (5 ft^3) of media and was also equipped with an automatic pneumatic backwashing mechanism. The total system flow was set at 3.8 m^3/day (0.7 gal/min) throughout the study period which was the flow at 0.7 gpm through the second experimental unit. The system flow was kept constant using on inline flow meter fed by a sump submersed in the first septic tank as in the previous experimental design. The recirculation flow rate ranged from 218 – 272 m^3/day (40 - 50 gal/min). A system schematic can be seen in Figure 3-10.

The influent wastewater was characterized as a moderate to high strength stream with average $CBOD_5$ and TSS concentrations at 373.6 and 510.0 mg/l, respectively. Total ammonia nitrogen concentrations in the influent wastewater were over 80 mg/l. Samples were taken at the influent and effluent ends of the experimental unit weekly. Sludge was discharged from both units also every week following sampling. Results show mean influent and effluent $CBOD_5$ concentrations at 311.8 and 48.7 mg/l, respectively. Organic loading to the entire system was between 3 to 5 kg/m^3.day with the assumption that there were no oxygen limitation conditions existing in the

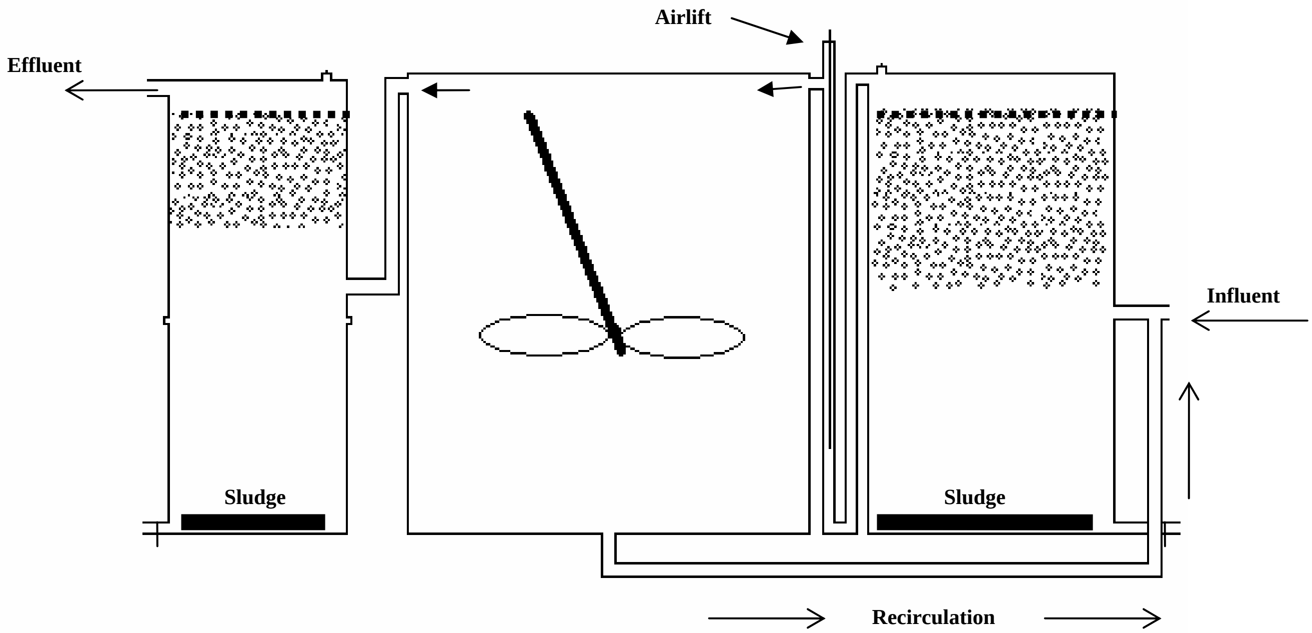


Figure 3-10. The experimental system was a sequential SLDM filtration configuration combining a roughing filter with a single pass unit targeting fine solids capture.

second filter. Total suspended solids loading to the entire system averaged 24.4 kg/m^3.day. The sequential treatment strategy proved beneficial to gross solids removal with total suspended solids decreasing from 529.5 mg/l to 26.3 mg/l. However, the reduction in total suspended solids was accompanied with an average $CBOD_5$ effluent quality above 40 mg/l. The results in Table 3-7 represent influent and effluent concentrations for the entire sequential system. Future studies should incorporate particle size analysis to gain an understanding of the particle size distribution present in the incoming wastewater stream. The size distribution pattern may influence media selection as well as system configuration.

These results were for high filtration rate multiple passes through the filter bed of the larger SLDM filter in addition to single pass at a lower filtration rate through the smaller SLDM unit. Total ammonia nitrogen conversion for the sequential treatment

Table 3-7. Average results for sequential SLDM filter treatment system for simultaneous BOD, TSS, and TAN removal.

Parameter	$CBOD_5$	TSS	TAN*
Influent (mg/l)	377.8 ± 89.4	529.5 ± 211.8	83.9 ± 31.6
(n)	(6)	(6)	(6)
Effluent (mg/l)	48.7 ± 23.2	26.3 ± 29.5	25.9 ± 13.0
(n)	(6)	(6)	(6)
% Removal	88.4 ± 4.6	94.5 ± 5.1	64.4 ± 21.7
(n)	(6)	(6)	(6)

* Mean Volumetric TAN Conversion = 1.01 kg/m^3.day ± 0.7

system averaged 1.01 kg/m^3.day at a mean effluent $CBOD_5$ level of 48.7 mg/l. Although effluent $CBOD_5$ concentrations averaged 48.7 mg/l, a nitrification inhibition phenomenon was not apparent using this sequential treatment arrangement. Percent removal for $CBOD_5$, TSS, and TAN for the entire system can be seen in Figure 3-11.

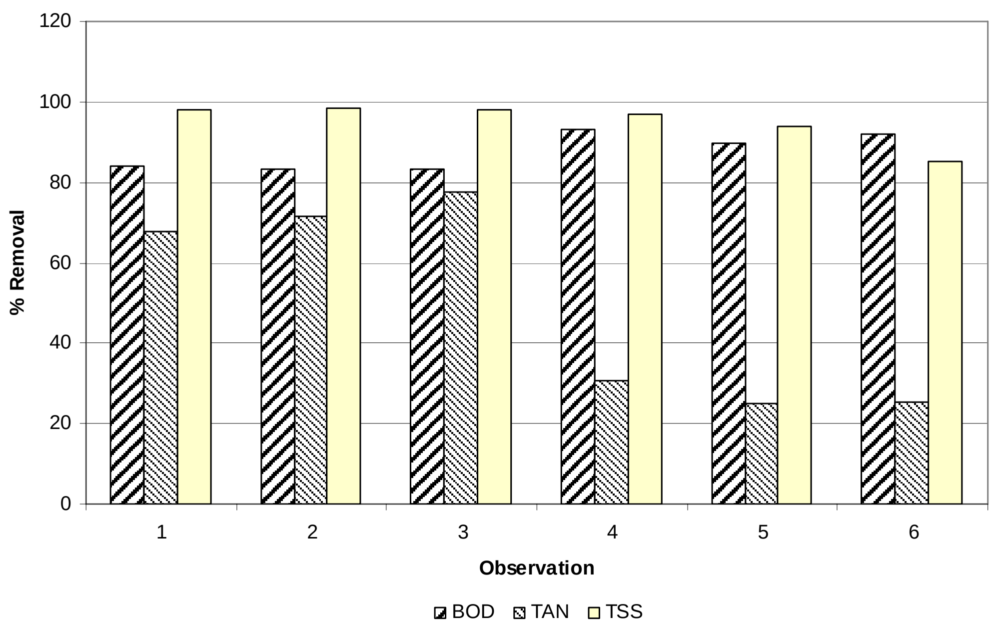


Figure 3-11. Performance of SLDM sequential treatment proved effective for removal of BOD and TSS as well as nitrification occurring in the presence of high organic levels.

CONCLUSIONS

SLDM filters can be used throughout the treatment train for bioclarification simultaneously reducing BOD, TSS, and TAN from primary and secondary effluents. These filters provide a robust treatment alternative where space and service opportunities are limited. Effluent $CBOD_5$ and TSS quality below 10 mg/l can be achieved at organic loadings up to 2.0 kg/m^3.day for domestic wastewater in warmwater conditions. Nitrification of the rock filter effluent was described by a zero order reaction rate with a maximum volumetric TAN conversion of 1.62 kg/m^3.day at effluent $CBOD_5$ concentrations under 15 mg/l. Also, under the same conditions of low organic loading, effluent TAN concentrations below 10 mg/l were measured with an applied TAN loading of 2.2 kg/m^3.day to the media bed. Nitrification was suppressed in the extended aeration / SLDM filter sequence to an average of 0.5 kg/m^3.day in the presence of an effluent $CBOD_5$ concentration in the range of 40 – 60 mg/l. Corresponding organic and TSS loading to the filter following the extended aeration unit averaged 3.6 and 6.7 kg/m^3.day, respectively. A recirculating SLDM filter used as a bioclarifier can reduce the gross BOD and TSS in high strength domestic wastewaters ($CBOD_5$ and TSS > 300 mg/l), and if followed by a single pass unit for fine solids capture, can reduce $CBOD_5$ and TSS by 88 % and 94 %, respectively. The average total ammonia nitrogen conversion attained for the sequential SLDM strategy was 1.01 kg /m^3.day at a $CBOD_5$ effluent in the range of 20 – 50 mg/l. Although over 90 percent of the TSS was removed with SLDM sequential treatment, $CBOD_5$ effluent concentrations remained above 40 mg/l for this particular application. Future studies should include particle size distribution data to determine the nature of the solids problem. Incorporating particle size information into current design approaches for wastewater treatment can provide momentum for further refinements in biological treatment processes.

CHAPTER 4: GLOBAL DISCUSSION

The consolidation of biological and physical unit operations using Static Low Density Media filters has demonstrated the ability to achieve complete secondary and tertiary treatment using an airlift recirculating bioclarifier in conjunction with proper media selection targeted to the intended treatment goal. SLDM filters, using the consolidation strategy, could replace more traditional treatment operations and processes such as activated sludge and trickling filters along with the associated clarification unit. SLDM filters require little maintenance when operated using airlifts for recirculation and aeration of the media bed, and adhering to the guidelines for substrate loading and operational techniques.

In earlier studies using SLDM filters for BOD and TSS removal from domestic wastewater, differences in system performance were found based on unit design and optimization of operating techniques (Wagener 2003). The findings from those studies, in addition to conclusions addressed in this thesis with respect to media selection and internal and external unit configuration, have facilitated in the forward evolution of SLDM filters for treating domestic wastewater.

ORGANIC LOADING CHARACTERISTICS

Proper design criteria for biofilters are based on a range of substrate loadings the particular system can handle while producing a high quality effluent. The organic loading, as previously described, for each experimental unit tested was calculated using the following equation:

$$\text{Loading} = \frac{S_i * Q_T}{V_{media}} \qquad \text{Equation 4.1}$$

Where S_i is the substrate entering the SLDM filter, Q_T is flow through the entire system, and V_{media} is the volume of filter media, not the filter hull volume. The relationship between organic loading and effluent $CBOD_5$ concentration can be used as a tool for comparison with other treatment technologies as well as related SLDM filter evaluations. Results from evaluations at both locations for this particular study are illustrated in Figure 4.1. The organic loading values were calculated using equation 4.1 and are expressed in units of kg/m^3.day.

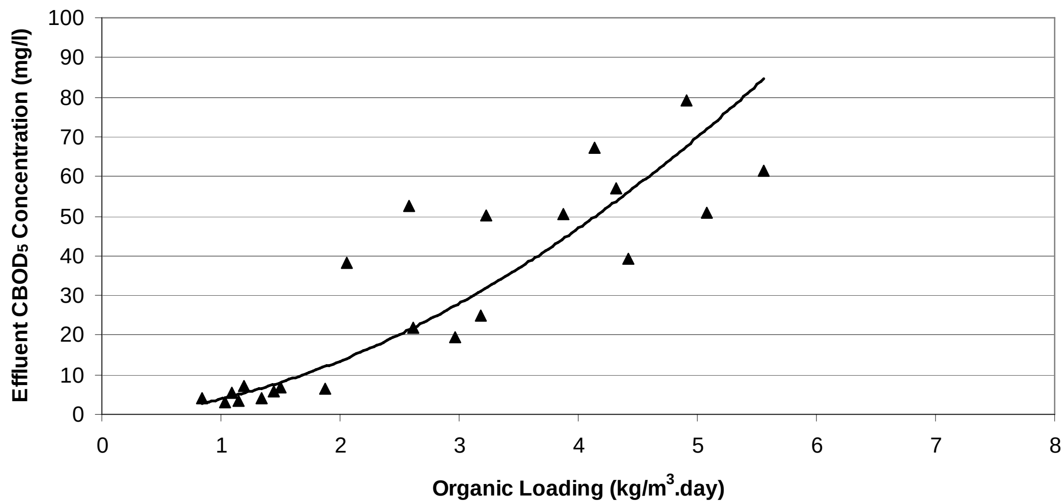


Figure 4-1. Volumetric organic loading remains a valuable design and comparison criterion

The data from P7a with EN media is shown along with similar studies performed by Wagener (2002) in Figure 4-2. The analysis was performed with data from P7b with KMT media showing a weaker relationship between the two parameters. The flatter slope of the Prototype 7 trend lines could be explained by an improved backwashing technique reducing the interference of TSS in filter effluent. Further refinement in design can be attributed to proper media selection enhancing fine solids capture lowering $CBOD_5$ effluents.

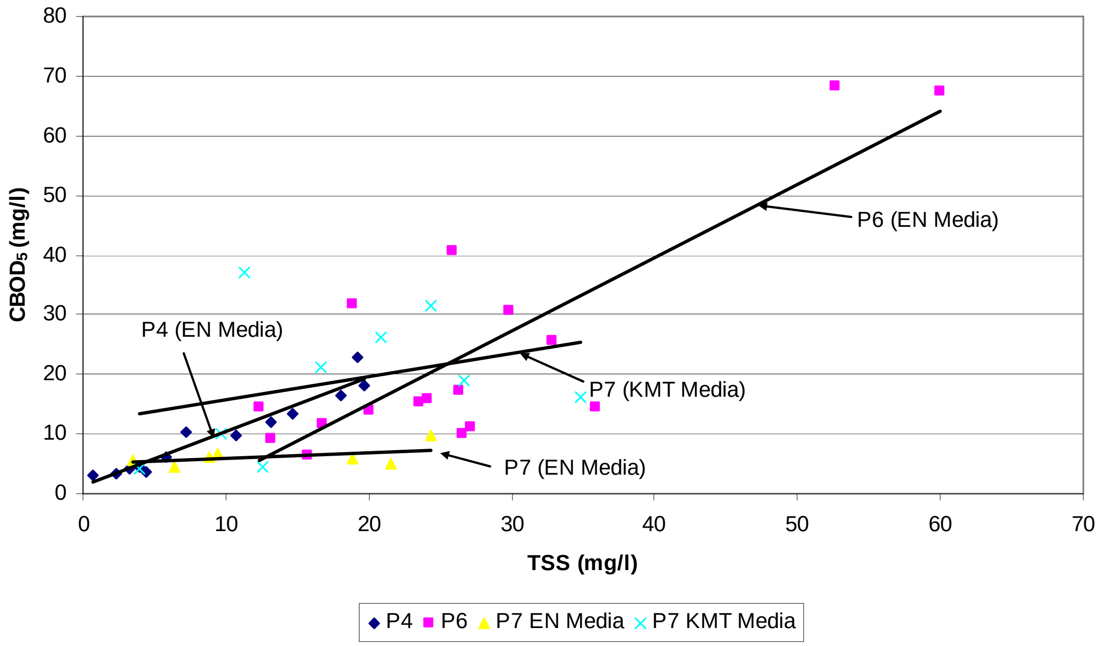


Figure 4-2. TSS control in filter effluents improves with design refinements and proper media selection

NITRIFICATION UNDER HIGH AND LOW SUBSTRATE REGIMES

SLDM filters applied in this study have proved effective for simultaneous removal of BOD and TSS in addition to effective nitrification in the presence of low and high levels of organics. Total ammonia nitrogen conversion capacities averaging 1.6 kg/m^3.day can be achieved under levels of low organic loading which are comparable to conversion capacities observed where SLDM filters have been applied in the aquaculture industry. At a TAN conversion capacity ranging from 1-2 kg/m^3.day in a low organic environment, effluent levels under 10 mg/l were observed. Due to the influent TAN concentrations ranging from 30 – 100 mg/l, future studies should look at VTR values where lower influent levels are present to determine if the zero order phenomenon occurs. Nitrification under higher levels of organics, namely over 100 mg/l $CBOD_5$, seemed to be sensitive to system configuration and placement within the treatment train according to the results in this evaluation.

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APPENDIX A:
DATA FROM PROTOTYPE 7 EXPERIMENTAL UNITS

P7a (EN Media)

Date	Day	3-Jul-02	9-Jul-02	10-Jul-02	11-Jul-02	16-Jul-02	19-Jul-02
	Time	4:00 PM	11:00 AM	11:00 AM	10:30 AM	11:30 AM	12:30 PM
Qr	m^3/d	161.5	217.6	226.7	227.4	226.6	192.3
Q	gal/day	394	484	478	356	391	381
BW Interval	hr	3	2.6	2.5	2.1	2.3	2.3
Temp	°C	29.2	28.8	29.2	29	29	30.6
$CBOD_5$							
Sy In	mg/l	73.4	67.5	117.4	87.3	87.6	84.4
Ry In	mg/l	< 6	5.8	8.3	3.2	5	< 3
Ry Out	mg/l	< 6	5.3	6.4	3.1	3.4	< 3
Sy Out	mg/l	6.5	6.5	9.9	3.8	6.2	3.6
DO							
DO in	mg/l	2.96	2.92	2.21	2.98	2.54	2.91
DO Out	mg/l	1.55	1.52	0.72	1.43	1.16	1.49
OUR	$kg/m^3 \cdot day$	2	2.69	2.98	3.12	2.75	2.42
BODr	$kg/m^3.day$		1.04	3.7	0.28	3.04	
BOD Bed	mg/l		5.57	7.35	3.16	4.2	
Bed Load	$kg/m^3.day$		11.21	16.55	6.48	9.92	
TSS							
Sy In	mg/l	48.4	42.1	46.8	30.0	58.3	35.8
Ry In	mg/l	9.9	6.6	6.7	3.7	4.7	3.3
Ry Out	mg/l	8	6.0	7	2.8	3.4	2.3
Sy Out	mg/l	8.8	6.0	9.4	2.5	4.2	2.8
Head Loss							
Top Screen	cm	0.3	0.3	0.3	0.3	0.3	0.3
Bed	cm	4	4	2	1.5	1	1.75
Bottom Screen	cm	0.5	0.5	0.3	0.3	0.3	0.3
Total	cm	5	5	2.5	1.6	1.2	2

Note: All results from analytical tests represent average results

$CBOD_5$ analysis was performed in triplicate with three dilutions

DO analysis was via Winkler Method and performed in triplicate

TSS analysis was performed in triplicate

Sy In and Sy Out refer to influent and effluent wastewater entering and exiting the entire system

Ry In and Ry Out refer to concentration before and after the media bed

* Began to use Ry Out as discharge from system

Top Screen = Head Loss Across Screen Above Media Bed
Bed = Head Loss Due to Media Bed
Bottom Screen = Head Loss Across Screen Below Media Bed
Total = Head Loss Due to Both Screens and Media Bed

Date	Day	31-Jul-02	2-Aug-02	7-Aug-02	13-Aug-02	14-Aug-02	15-Aug-02
	Time	3:30 PM	1:30 PM	1:30 PM	2:30 PM	1:30 PM	2:30 PM
Qr	m^3/d	170.2	173.5	157.6	163.5	169.5	171
Q	gal/day	483	201	696	514	412	401
BW Interval	hr	2.4	2	2.1	2.3	2	2
Temp	°C	29.6	29.6	30.1	29.1	29	28.8
$CBOD_5$							
Sy In	mg/l		124.7		71.3	104.9	118.6
Ry In	mg/l		4.6	8.9	5.1	6.6	6.0
Ry Out	mg/l		4.1	9.1		5.7	
Sy Out	mg/l		5.2	11.3	5.7	7.9	6.9
DO							
DO in	mg/l	2.87	3.00	2.05	2.97	2.63	2.41
DO Out	mg/l	1.28	1.52	0.76	1.52	1.22	0.78
OUR	$kg/m^3 \cdot day$	2.38	2.26	1.80	2.08	2.11	2.45
BODr	$kg/m^3.day$		0.70			1.33	
BOD Bed	mg/l		4.32	8.98		6.12	
Bed Load	$kg/m^3.day$		4.32	8.98		6.12	
TSS							
Sy In	mg/l	82.5	78.2	32.7	45.7	55.0	61.7
Ry In	mg/l	6.4	5.3	12.7	7.0	5.2	7.3
Ry Out	mg/l	4.1	7.0	10.4	4.5	4.5	4.3
Sy Out	mg/l	5.0	8.0	20.0	5.5	4.5	5.0
Head Loss							
Top Screen	cm	0.3	0.3	0.3	0.3	0.3	0.3
Bed	cm	1.5	1.5	1.5	1.5	1.3	2
Bottom Screen	cm	0.3	0.3	0.3	0.3	0.3	0.3
Total	cm	1.7	1.7	1.7	1.7	1.4	2.5

Date	Day	20-Aug-02	21-Aug-02	27-Aug-02	10-Sep-02	11-Sep-02	17-Sep-02
	Time	3:00 PM	12:00 PM	11:30 AM	12:30 PM	12:30PM	12:30PM
Qr	m^3/d	143.2	179.7	186.0	185.09	177.31	141.8
Q	gal/day	380	493	292	306	535	520
BW Interval	hr	2.2	2	2.4	2.3	2.5	3
Temp	°C	31.5	31	30	29.5	30	29.8
$CBOD_5$							
Sy In	mg/l	94.3	90.9	137.7	95.6	86.1	89.6
Ry In	mg/l	7.9	7.5	5.3		6.43	8.35
Ry Out	mg/l	7.1	6.7	4.2		5.75	9.68
Sy Out	mg/l	*	*	*		*	*
DO							
DO in	mg/l	2.37	2.25	2.66	3.22	2.40	3.51
DO Out	mg/l	0.82	0.81	1.12	1.74	1.18	1.55
OUR	kg/m^3·day	1.97	2.28	2.53	2.42	1.90	2.45
BODr	kg/m^3.day	0.99	1.36	1.86		1.06	
BOD Bed	mg/l	7.50	7.12	4.77		6.09	9.01
Bed Load	kg/m^3.day	9.97	11.97	8.75		10.07	10.44
TSS							
Sy In	mg/l	74.1	42.1	98.3	99.7	49.5	58.1
Ry In	mg/l	7.8	9.9	5.0	16.0	7.8	15.6
Ry Out	mg/l	4.9	5.3	3.9	4.7	18.8	24.4
Sy Out	mg/l	*	*	*	*	*	*
Head Loss							
Top Screen	cm	0.3	0.3	0.3	0.3	0.3	0.2
Bed	cm	2	1.5	1.5	2.0	2.0	1.4
Bottom Screen	cm	0.3	0.3	0.3	0.1	0.2	2.0
Total	cm	2.5	2.1	1.8	2.8	2.5	4.0

Date	Day	19-Sep-02	20-Sep-02	24-Sep-02	11-Oct-02	23-Oct-02	24-Oct-02
	Time	11:00AM	10:30AM	1:30PM	11:00AM	4:00 PM	11:30AM
Qr	m^3/d	113.17	144.08	135.41	31.69	91.23	
Q	gal/day	416	307	557	198	256	203
BW Interval	hr	3	2.75	3	3	2.7	
Temp	°C	29.5	29	27.8	25.8	23.8	
$CBOD_5$							
Sy In	mg/l	108.1	104.4	77.7	99.6	92.9	95.3
Ry In	mg/l	7.94	5.46	8.23	4.85		
Ry Out	mg/l	6.20	6.23	6.71	5.02		
Sy Out	mg/l	*	*	*	*		
DO							
DO in	mg/l	4.00	3.40	3.52	5.93	5.57	
DO Out	mg/l	1.92	1.67	1.79	2.32	3.68	
OUR	$kg/m^3 \cdot day$	2.08	2.20	2.06	1.01	1.52	
BODr	$kg/m^3.day$	1.74		1.82			
BOD Bed	mg/l	7.07	5.85	7.47	4.93		
Bed Load	$kg/m^3.day$	7.93	6.94	9.83	1.36		
TSS							
Sy In	mg/l		138.67	98.67	82.22	55.77	51.19
Ry In	mg/l		10.50	23.87	20.00	4.14	5.33
Ry Out	mg/l		8.83	9.42	21.60	4.58	4.89
Sy Out	mg/l		*	*	*	*	*
Head Loss							
Top Screen	cm	0.2	0.1	0.2	8.5	0.1	
Bed	cm	1.0	1.8	1.0	1.0	7.0	
Bottom Screen	cm	3.5	2.5	4.0	0.1	0.5	
Total	cm	4.0	4.6	5.2	9.6	7.6	

Date	Day Time	31-Oct-02 10:30PM	1-Nov-02 3:30PM	7-Nov-02 12:00PM	12-Nov-02 12:00 PM	15-Nov-02 3:00PM	19-Nov-02 11:00AM
Qr	m^3/d	114.45	109.82				59.40
Q	gal/day	237	388	181	223	115	141
BW Interval	hr	2.4	2.5	2.6	2.7	2.3	2.8
Temp	°C	22	21	18	21	20	17
$CBOD_5$							
Sy In	mg/l	108.9	137.1	124.0			136.5
Ry In	mg/l	4.50	7.64	3.54			8.35
Ry Out	mg/l		6.84	4.51			5.50
Sy Out	mg/l		*	*			*
DO							
DO in	mg/l	6.00	5.53	7.16			6.10
DO Out	mg/l	3.98	3.79	5.15			3.79
OUR	kg/m^3·day	2.04	1.69				1.21
BODr	kg/m^3.day		0.78				1.49
BOD Bed	mg/l		7.24	4.02			6.92
Bed Load	kg/m^3.day	4.55	7.40				4.38
TSS							
Sy In	mg/l	88.10		73.33			74.50
Ry In	mg/l	7.81		6.93			
Ry Out	mg/l	6.76		6.40			
Sy Out	mg/l	*		*			
Head Loss							
Top Screen	cm	0.1	0.1	0.1	0.1		0.1
Bed	cm	0.8	1.0	0.3	0.8		0.3
Bottom Screen	cm	5.0	7.0	10.0	8.5	0.3	13.0
Total	cm	5.9	8.0	10.4	9.4		13.4

Date	Day	24-Oct-02	26-Nov-02
	Time	11:30AM	2:30PM
Qr	m^3/d	87.33	67.20
Q	gal/day		322
BW Interval	hr	3	3
Temp	°C	23.5	18
$CBOD_5$			
Sy In	mg/l	95.3	127.5
Ry In	mg/l		8.53
Ry Out	mg/l		
Sy Out	mg/l		
DO			
DO in	mg/l	5.80	6.71
DO Out	mg/l	4.57	3.57
OUR	kg/m^3·day	0.95	1.86
BODr	kg/m^3.day		
BOD Bed	mg/l		
Bed Load	kg/m^3.day		5.06
TSS			
Sy In	mg/l	51.19	85.78
Ry In	mg/l	5.33	5.00
Ry Out	mg/l	4.89	3.47
Sy Out	mg/l	*	*
Head Loss			
Top Screen	cm	0.1	0.1
Bed	cm	1.3	0.5
Bottom Screen	cm	6.0	9.5
Total	cm	7.4	10.0

P7b (KMT Media)

Date	Day	10-Sep-02	11-Sep-02	17-Sep-02	19-Sep-02	20-Sep-02	24-Sep-02
	Time	1:00pm	12.30PM	12:30PM	11:00AM	10:30AM	1:30PM
Qr	m^3/d		232.68	104.46	185.63	192.55	177.99
Q	gal/day	554.8	752.8	735.6	623.5	436.8	734.2
BW Interval	hr	2.6	2.8	2.8	3	3	3
Temp	°C		31	30	30	30	28.2
$CBOD_5$							
Sy In	mg/l		86.10	89.60	108.10	104.40	77.70
Ry In	mg/l			12.31	18.72	17.54	19.76
Ry Out	mg/l			9.93	18.04	16.21	18.84
Sy Out	mg/l						
DO							
DO in	mg/l		1.18	2.41	2.47	2.00	2.79
DO Out	mg/l		0.25	0.24	1.48	1.08	1.86
OUR	$kg/m^3 \cdot day$		1.92	2.00	1.61	1.56	1.46
BODr	$kg/m^3.day$			2.19	1.12	2.26	1.46
BOD Bed	mg/l			11.12	18.38	16.88	19.30
Bed Load	$kg/m^3.day$			11.35	30.67	29.80	31.04
TSS							
Sy In	mg/l	99.68	49.54	58.10		138.67	98.67
Ry In	mg/l	11.53	23.33	5.87		34.17	29.17
Ry Out	mg/l	13.00	20.93	9.62		34.80	26.67
Sy Out	mg/l						
Head Loss							
Top Screen	cm		0.2	0.1	0.2	0.1	0.1
Bed	cm		0.5	7.5	1.25	1	1
Bottom Screen	cm		0.2	0.1	0.2	0.1	0.1
Total	cm		1	7.7	1.5	1.1	1.2

Date	Day	11-Oct-02	17-Oct-02	18-Oct-00	23-Oct-02	24-Oct-02	31-Oct-02
	Time	11:00AM	12:00PM	12:00 AM	4:00Pm	11:30AM	10:30AM
Qr	m^3/d	105.40	108.96	104.90	99.81	155.33	12.76
Q	gal/day	275	250	300	332.4	234.7	435.4
BW Interval	hr	2.7	2.6	2.8	2.6	2.5	2.6
Temp	°C	25.5	23	24.5	25	24.5	23
$CBOD_5$							
Sy In	mg/l	99.60	125.10		92.90	95.30	108.90
Ry In	mg/l	5.33			5.07		42.10
Ry Out	mg/l	4.49	26.27		4.13		37.03
Sy Out	mg/l	*	*		*		*
DO							
DO in	mg/l	6.37	3.83	5.75	4.97	5.62	0.66
DO Out	mg/l	5.73	2.90	4.97	4.08	4.82	0.11
OUR	kg/m^3·day	0.59	0.90	0.73	0.78	1.10	0.06
BODr	kg/m^3.day	0.79			0.83		0.57
BOD Bed	mg/l	4.91			4.60		39.57
Bed Load	kg/m^3.day	4.96			4.46		4.74
TSS							
Sy In	mg/l	82.22	63.81	52.10	55.77	51.19	88.10
Ry In	mg/l	13.33	24.83	8.11	26.80	4.40	14.69
Ry Out	mg/l	12.53	20.83	7.83	3.94	5.07	11.30
Sy Out	mg/l	*	*	*	*	*	*
Head Loss							
Top Screen	cm	0.1	0.1	0.1	0.1	0.1	0.1
Bed	cm	0.5		2	0.1	4	10
Bottom Screen	cm	0.1		0.1		0.1	0.1
Total	cm	0.7	1.9	2.2	5.2	4.2	10.1

Date	Day	7-Nov-02	12-Nov-02	15-Nov-02	19-Nov-02	26-Nov-02
	Time	12:00PM	12:00pm	3:00 PM	11:00 AM	3:00pm
Qr	m^3/d	101.62			98.97	115.19
Q	gal/day	543.8	365.4	194.2	277.6	532.2
BW Interval	hr	2.9	2.6	3.1	2.9	3.2
Temp	°C	19	22	22	18.8	
$CBOD_5$						
Sy In	mg/l	124.90		152.20	136.50	127.50
Ry In	mg/l	15.95		67.30	32.28	26.06
Ry Out	mg/l	21.31			31.63	24.16
Sy Out	mg/l	*			*	*
DO						
DO in	mg/l	4.99			4.45	4.25
DO Out	mg/l	4.58			4.18	3.87
OUR	kg/m^3·day	0.37			0.23	0.39
BODr	kg/m^3.day				0.57	
BOD Bed	mg/l	18.63			31.95	25.11
Bed Load	kg/m^3.day	14.30			28.19	26.49
TSS						
Sy In	mg/l	73.33		83.11	74.50	85.78
Ry In	mg/l	15.71		33.89	26.20	60.56
Ry Out	mg/l	16.67		20.47	24.33	
Sy Out	mg/l					
Head Loss						
Top Screen	cm		0.1			
Bed	cm		0.1		0.25	0.5
Bottom Screen	cm	0.25	0.5	0.25	0.1	1
Total	cm	0.75	0.7		0.35	1.5

APPENDIX B:
PROTOTYPE 7 EXPERIMENTAL REPORT

Final Report: Delta 7 Prototype

Experimental Report Number 2003.03

Steven M. Bellelo

June 28, 2003

Louisiana State University
Institute for Ecological Infrastructure Engineering

Abstract

From June 2002 to May 2003, the Delta 7 Experimental Units were in operation at the Delta Environmental Test Site, located in Denham Springs, Louisiana. During this period, the system was operated and evaluated at various hydraulic and organic loading rates, recirculation rates, backwash intervals, and ambient temperatures. Samples were subject to various analytical analyses, which were conducted in triplicate according to Standard Methods for the Examination of Water and Wastewater (APHA, 1995). Averaged results from this evaluation are presented.

Static Low-Density Media Filters

Static low-density media (SLDM) filters are known in the aquaculture community as Floating Bead Filters (FBFs). The units are now widely employed as clarifiers or bioclarifiers in support of high-density recirculating production and holding systems for fish, reptiles, and crustacea (Malone and Beecher, 2000; DeLosReyes and Lawson, 1996). The units are normally operated with the floating bed in a packed or static mode. In the packed bioclarification mode, the units concurrently provide solids capture, carbonaceous BOD removal, and nitrification. The beds are periodically expanded for removal of accumulated solids and excess biofilm (Malone and Beecher, 2000; Cooley, 1979). Backwashing or expansion of a bead bed can be accomplished by hydraulic, pneumatic or, mechanical means. In most aquaculture applications, nitrification capacity limits bioclarifier performance; thus, most of the historic research has focused on improving the nitrification capacity (Sastry, 1999; Malone *et al*.,1993).

The low-density plastic media acts as a carrier for biofilm and as a physical separation mechanism for solids. Heterotrophic bacteria attach themselves to the beads and utilize the organic matter in the waste stream as a carbon source for growth, while autotrophic, nitrifying bacteria convert ammonia to nitrate under conditions of low organic loading (Zhang et al, 1995). Concurrently, suspended solids in the waste stream are captured in the bed via surficial straining, deep bed filtration, and adsorption as the waste stream travels upward though the bead bed.

The floating bead filters (FBF's) are expandable granular filters that display a bioclarification behavior similar to sand filters (Malone et al. 2000). FBF's utilize floating plastic medias of different shapes with a high specific area (SSA m^2/m^3) and porosity to biologically and physically filter wastewater supplies very efficiently. In general the high specific surface area of the floating plastic medias provide an excellent surface for heterotrophic and autotrophic bacterial growth with a minimal amount of filter volume (smaller filters = less expensive filters). The limited porosity of the filter bead bed allows the filter to capture large amounts of solids (> 50 µm & 40 –50 % < 10 µm) through straining, settling, interception, and adsorption on a single pass basis. The

physical effect of straining, settling, interception, and adsorption is furthered magnified in multiple pass systems due to the effect of increased solids buildup and biofilm formation (decreased porosity) (approximately complete clarification < 1 NTU). The S.S.A, porosity, and shape of the floating plastic medias used in FBF's vary greatly.
FBF's have two modes of operation known as the packed or filtration mode and expanded or backwashing mode. In the filtration mode the floating media is packed against the top of the filter by the buoyancy of the floating media and the force of the water flowing past the bead bed. When activated, the floating media becomes coated with a thin film layer of heterotrophic and autotrophic aerobic bacteria, which will oxidize dissolved organic contaminants (energy source) and convert toxic ammonia to nitrate (nitrification process) in water passing through the bead filter bed (Figure 1.).

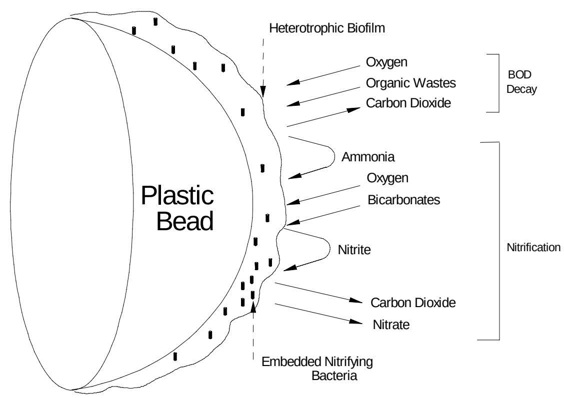


Figure 1. Representation Of Bacterial Biofilm Coating Floating Plastic Media (Malone, 1995)

The optimal biofilm thickness (effective X) reported for most types of floating media is approximately 300 μm (Malone, 2001). A biofilm thickness approximately equal to or greater than 300 μm hinders diffusion of dissolved oxygen (electron acceptor) to underlying layers of bacteria. When the underlying layers of bacteria are unable to extract the necessary amount of dissolved oxygen from the passing water supply, the underlying bacterial layers become dormant or die-off. This can possibly lead to the separation of upper layers of bacteria from the supporting media, which leads to biofouling. Excessive biofouling and increased solids buildup lead to mean cell residence time (MCRT) problems and a loss of hydraulic conductivity. In order to maintain hydraulic conductivity and avoid MCRT problems the packed bead bed must be cleaned by backwashing.

Backwashing FBF's is relatively easy compared to the traditional down-flow filters (trickling and sand filters) and requires a minimal amount of water. Backwashing expands the bead bed and increases turbulence and collisions among the bead media to abrade excess bioflilm and prevent biofouling. The once trapped solids (if any solids are present in the system) and excess biofloc are then allowed to settle at the bottom of the filter where they are removed as sludge.

Materials and Methods

The Delta 7a prototype was in operation from June 2002 to May 2003. This filter consisted of a113.3L ($4ft^3$) bead filter inside of an equalization tank. The filter media used was 3 to 5 mm in diameter, with a density of 0.90 kg/L, a porosity of 0.55, and with a total specific surface area of 1100 to 1250 m^2/m^3 (Malone *et al*., 1993). The Delta 7b prototype was in operation from August 2003 to December 2003. The filter configuration for both filters was the same except for the media used. Delta 7b contained media 10 mm in diameter, with a density of 0.90 kg/L, a porosity of 0.75, and a total specific surface area of 670 m^2/m^3. The Delta 7 experimental units had a total capacity of 1.78 m^3. The resulting effect was a dynamic system with four separate compartments allowing simultaneous water exchange. The four compartments included an outer equalization tank (205 gal), an inner polishing chamber (174 gal), a bead bed (30 gal), and a sludge collection chamber (60 gal). A 3 in airlift was used to circulate water between the polishing chamber and the bead bed. The water was also backmixed via the same airlift back into the outer equalization tank. The prototypes 7a and 7b were configured in the manner shown in Figure 2.

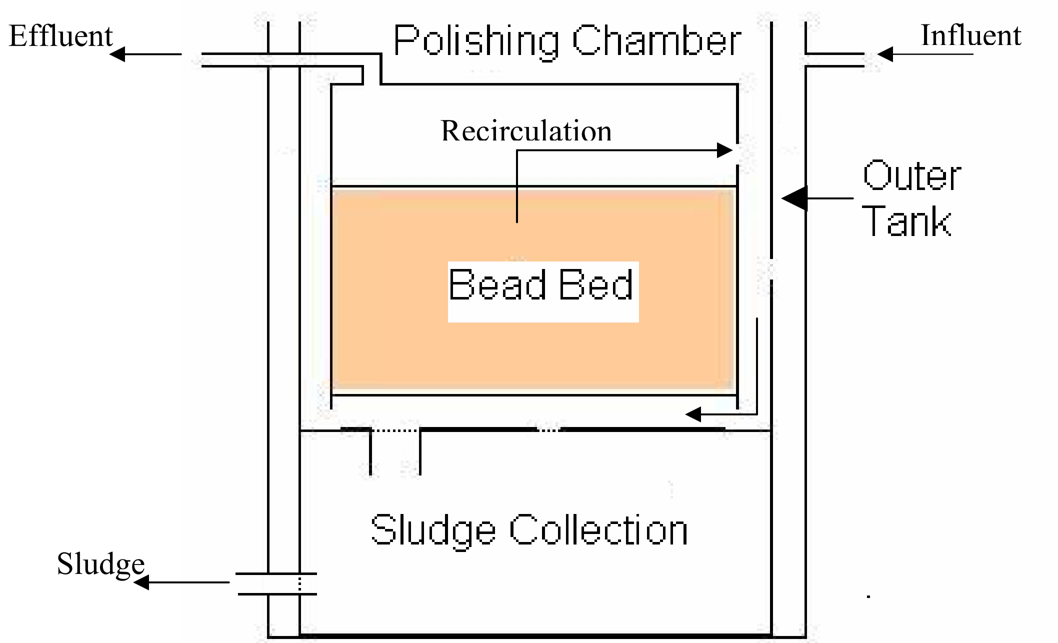


Figure 2. Diagrammatic Representation Of The Experimental System

This site is subject to highly variable flow characterized by morning and afternoon peaks and no overnight flow; hence, the need for equalization basins. The raw wastewater enters a large tank that acts as a primary clarifier, before it flows to the experimental units. Following the filter-tank combination was an effluent holding tank. This effluent tank contained a trash pump and was followed by a meter so that the total volume exiting through the system could be determined. The influent wastewater characteristics to the experimental unit can be seen in Table 1

Table 1. Influent Wastewater Characteristics

Parameter	Average Value
$CBOD_5$, mg/L	104
(n)	(45)
TSS, mg/L	61
(n)	(42)
Temperature C	23.3
(n)	(47)

The entire system was operated for more than one month in an acclimation mode, prior to testing. During this period wastewater was circulated through the filter, but the backwashing frequency was lowered so that bacteria could populate the biofilm carrier.

Analytical Methods

Temperature, pH, and flow measurements were recorded along with other operational parameters, such as backwash frequency, during each sampling event. Water quality parameters were tested in triplicate according to Standard Methods for the Examination of Water and Wastewater and include the following: $CBOD_5$ (5210B), DO (4500-O C), TSS (2540 D), and VSS (2540 E) (APHA, 1995).

Sampling Procedures

Sampling procedures can be found in the Delta Prototype 6 Experimental Report (Wagener, 2002). Since prototype 7 had one airlift, recirculation and backmix flow rates were measured in triplicate from that airlift. Head loss measurements were taken at three different points in the system. Pitot tubes were used to measure head loss in centimeters. These were the only differences in sampling procedures referenced from the Delta Prototype 6 Experimental Report.

Results

Experimental results for the delta prototype 7 units were divided into 2 main data sets for each unit. The results from the delta 7a data set have shown carbonaceous biochemical oxygen demand (CBOD) concentrations to decrease from 101 mg/L to 5 mg/L on average for this period and through multiple passes of the filter. Total suspended solids

(TSS) concentrations have been shown to decrease from 66 mg/L to 7 mg/L on the average. The results from the delta 7b data set have shown CBOD concentrations to decrease from 111 mg/L to 19 mg/L on average. TSS concentrations for Delta 7b have been shown to decrease from 77 mg/L to 19 mg/L on the average. Results for both prototypes can be found in Table 2. The results in Table 2 are for multiple passes through the filter bed. A complete set of raw data can be found in Appendix A.

Table 2. Average Results for Both Prototypes

Experimental Prototype	$CBOD_5$			TSS		
	Total Load (kg/m^3.d)	Effluent (mg/L)	% Removal	Total Load (kg/m^3.d)	Effluent (mg/L)	% Removal
BF-7a	1.2	5.9	94.3	0.8	7.3	87.2
(n)	(27)	(19)	(18)	(27)	(27)	(26)
BF-7b	1.6	19.4	82.9	1.4	18.9	81.6
(n)	(15)	(12)	(12)	(15)	(15)	(15)

The operational parameters for the data reported above can be found in Table 3.

Table 3. Operational Parameters for Both Prototypes

Experimental Prototype	Filtration Rate (m/h)	Retention Time (min)		Oxygen Uptake Rate (kg/m^3.d)
		One Pass	**Total**	
BF-7a	21.1	0.73	90.7	2.12
(n)	(28)	(28)	(27)	(28)
BF-7b	17.5	1.16	89.7	0.93
(n)	(15)	(15)	(15)	(15)

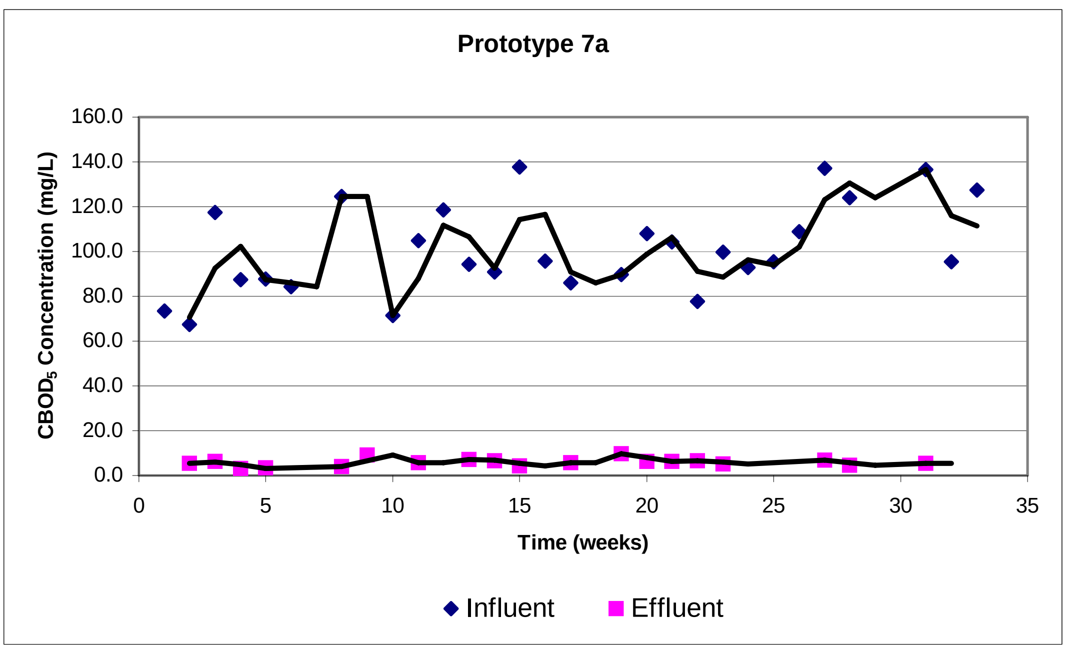
Table 4. Single Pass Results

Experimental Prototype	CBOD$_5$		TSS	
	Bed Loading (kg/m^3.d)	Removal %	Bed Loading (kg/m^3.d)	Removal %
BF-7a (n)	8.6 (22)	16.31 (14)	10.7 (25)	27.55 (20)
BF-7b (n)	18.3 (11)	9.31 (10)	25.5 (13)	21.83 (7)

The System and Bed Loading Rate formulas can be found in Delta Prototype 6 Experimental Report (Wagener, 2002).

Discussion

The performance of both Delta 7 prototypes was evaluated over the entire study period. A time series graph of CBOD$_5$ influent and effluent quality for both prototypes can be seen in Figure 3 and 4. Effluent concentrations remained stable for prototype 7a despite the dynamic nature of the influent wastewater concentration.



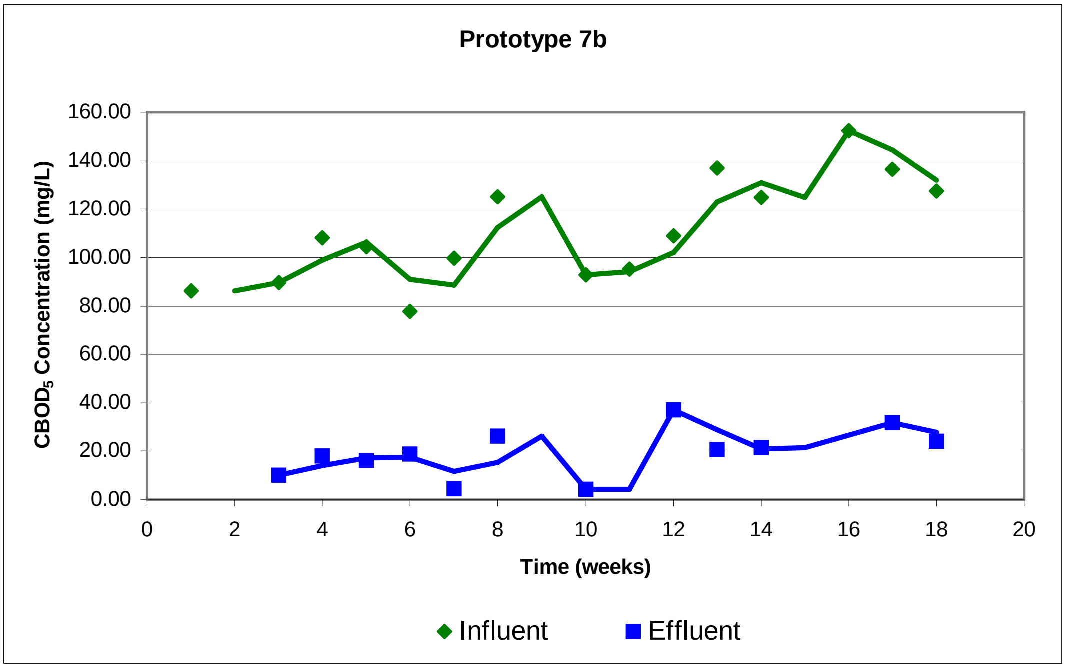
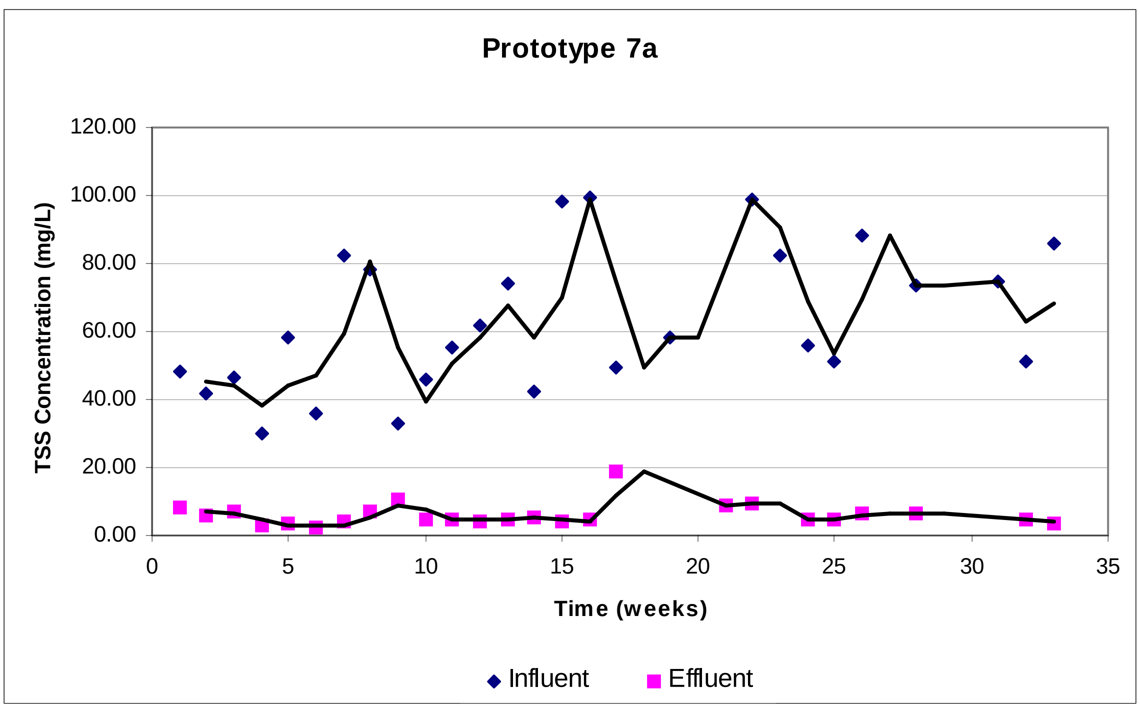


Figure 3 and 4. CBOD$_5$ Influent and Effluent Quality Over Length of Study Period

TSS concentrations throughout the study period can be seen in Figure 5 and 6. Solids capture performance in prototype 7a could be attributed to media characteristics.



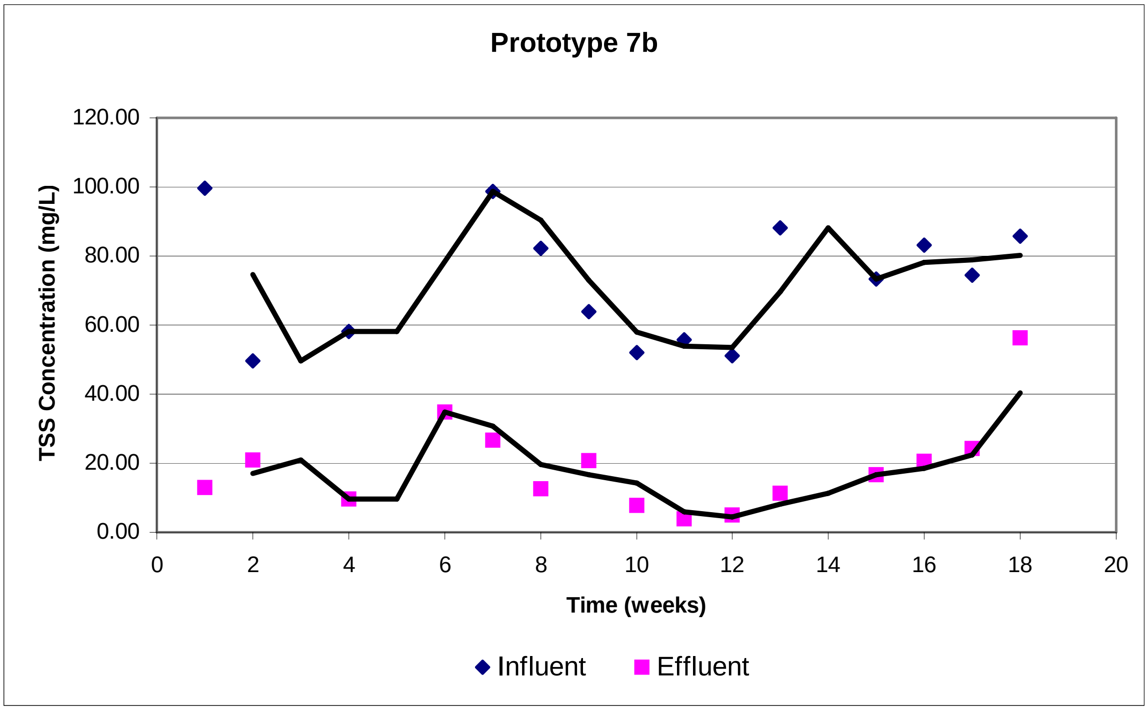
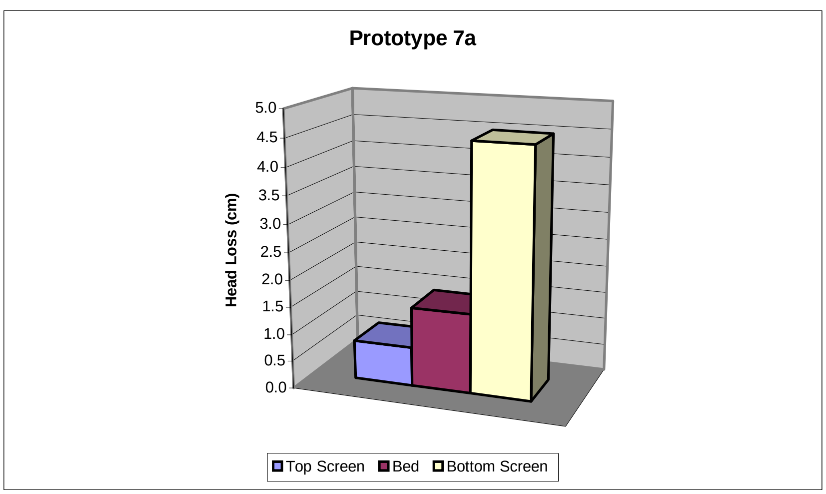


Figure 5 and 6. TSS Influent and Effluent Quality Over Length of Study Period

Head loss across the bottom screen was much more evident in prototype 7a. The average magnitude of head loss across both screens and the bead bed can be seen in Figure 7 and 8. Clogging of the bottom screen in prototype 7a became an issue towards the later part of the study period.



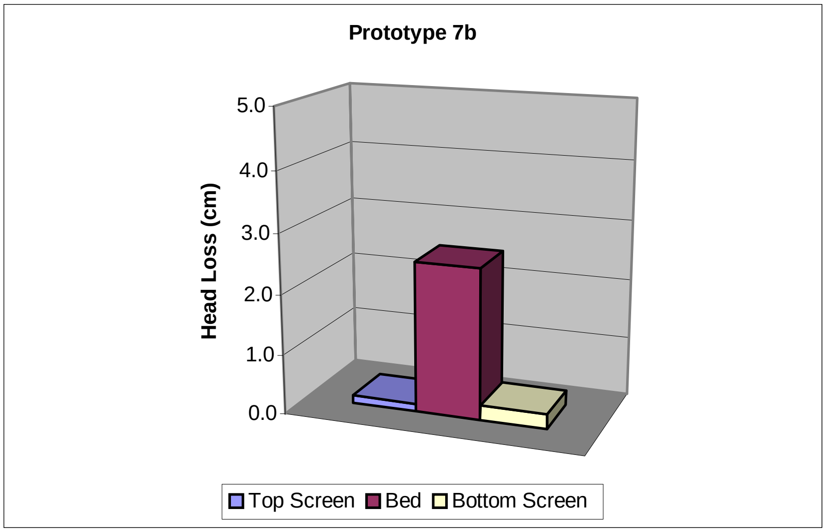


Figure 7 and 8. Average Head Loss for Prototypes 7a and 7b.

Conclusions

The ability to consolidate treatment processes, as in a SLDM filter, could reduce treatment cost and efficiency avoiding unit operation configurations. Such technology could significantly broaden decentralized treatment options. Further studies could possibly propel SLDM filters to the forefront of future wastewater treatment. Data from Delta #7 and previous prototypes have built a foundation for future study. Such minor issues as screen clogging and optimal filter configuration can be overcome.

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APPENDIX C:
DATA COLLECTED FORM LTRC REST AREA

Nitrification of Rock Filter Effluent

Obs Point	1	2	3	4	5
TAN $_{in}$	90.4	80.2	103.0	107.0	100.0
TAN $_{out}$	67.6	61.0	78.3	65.0	90.8
$CBOD_{5in}$	8.1		8.3	7.8	
$CBOD_{5out}$	10.4		9.7	9.2	
TSS_{in}	12.3		10.5	10.2	
TSS_{out}	8.5		7.5	8.4	
TAN Loading (kg TAN /m^3.day)	4.35	3.86	4.96	5.15	4.81
VTR (kg TAN /m^3.day)	1.09	0.93	1.19	2.02	0.44

Obs Point	6	7	8	9	10
TAN $_{in}$	51.2	56.9	67.3	63.7	30.0
TAN $_{out}$	30.1	11.8	15.7	9.3	1.3
$CBOD_{5in}$	7.9		8.2		7.8
$CBOD_{5out}$	11.2		9.6		10.8
TSS_{in}	11.5		11.6		10.4
TSS_{out}	7		9.1		8.7
TAN Loading (kg TAN /m^3.day)	2.46	2.74	3.24	3.06	1.44
VTR (kg TAN /m^3.day)	1.01	2.17	2.48	2.62	1.38

Obs Point	11	12	13	14	15
TAN $_{in}$	41.8	54.7	47.7	33.6	33.8
TAN $_{out}$	0.7	5.9	18.5	0.8	0.4
$CBOD_{5in}$					
$CBOD_{5out}$					
TSS_{in}					
TSS_{out}					
TAN Loading (kg TAN /m^3.day)	2.01	2.63	2.30	1.62	1.63
VTR (kg TAN /m^3.day)	1.98	2.35	1.40	1.58	1.61

Extended Aeration Followed by Static Low Density Media Filter

Date		7-Feb-03	17-Feb-03	24-Feb-03	7-Mar-03	14-Mar-03
Time		2:00 PM	3:00 PM	11:00 AM	2:00 PM	11:30 AM
Temp ˚C	A.S. Unit	12.2	11.9	17.0	22.0	19.5
	SLDM Filter	11.8	11.6	16.8	21.5	19.5
$CBOD_5$ (mg/L)	Sy In	145.0	170.4	204.6	156.9	186.0
	ML/SS			70.8	54.9	82.7
	Filter In		41.2	61.1	40.6	69.7
	Sy Out	41.9	21.9	50.4	52.6	39.3
TSS (mg/L)	Sy In	67.14	116	131.22	100	125.56
	ML/SS		78.67	109.83	95.83	428.89
	Filter In	105.78	80	89.17	68.33	118.67
	Sy Out	93.64	50.16	70	76.67	97.5
TAN (mg/L)	Sy In	113	97.3	83.1	98.4	104
	ML/SS	n/a	16.1	64.85	74	63.65
	Filter In	31.1	12.8	68	74.7	63.7
	Sy Out	21.2	7.52	63.7	67.5	51.9

Date		28-Mar-03	5-Apr-03	11-Apr-03
Time		12:00 PM	11:00 AM	1:00 PM
Temp ˚C	A.S. Unit	21.8	21.9	17.4
	SLDM Filter	22.8	21.9	18.9
$CBOD_5$ (mg/L)	Sy In	250.1	263.6	240.2
	ML/SS	173.4	174.0	112.2
	Filter In	68.1	32.4	87.6
	Sy Out	57.1	38.3	61.4
TSS (mg/L)	Sy In	125.83		
	ML/SS	703.33		
	Filter In	166.24		
	Sy Out	142.94		
TAN (mg/L)	Sy In	120	150	
	ML/SS	28	27	
	Filter In	27	28	
	Sy Out	23	19.5	

High Rate External Tank Recirculation with SLDM Filter

Date		25-Nov-03	2-Dec-03	16-Dec-03	6-Jan-04	20-Jan-04
$CBOD_5$ (mg/l)	In	311.5	473.5	399	286	490
	Out	50.2	79.2	67.2	19.4	50.9
TSS (mg/l)	In	329	849	627	262.5	550
	Out	6.0	14.0	13.0	8.0	34.0
TKN (mg/l)	In	135.5	173		98.7	112.7
	Out	9.71	18		35.8	64
TAN (mg/l)	In	100.9	140.25	65.85	55.2	68
	Out	9.07	16.8	14.7	24.8	39.8
NO_3 (mg/l)	In	0.185	0.165	0.315	0.355	0.345
	Out	11.5	9.12	33.7	31.4	30.3

Date		2-Feb-04
$CBOD_5$ (mg/l)	In	307
	Out	25
TSS (mg/l)	In	559.5
	Out	83.0
TKN (mg/l)	In	134.5
	Out	n/a
TAN (mg/l)	In	73.1
	Out	39.2
NO_3 (mg/l)	In	0.36
	Out	29.6

VITA

Born on January 25, 1977, in Baton Rouge, Louisiana, Steven M Bellelo is the son of Victor and Pearl Bellelo. He was raised in a small town, Maringouin, Louisiana, which is west of the Mississippi river. Steven has two older brothers, Richard and James, who live in Baton Rouge and nearby Brusly. He graduated from Livonia High School in 1995 and received his bachelor of science in microbiology from Louisiana State University in 2000. Steven applied to graduate school in civil and environmental engineering for the Fall 2001 semester. He was awarded an assistantship under the supervision of Dr. Ronald Malone. Steven has been a full time graduate student at Louisiana State University since August 2001, and is presently a candidate for the degree of Master of Science in Civil Engineering.